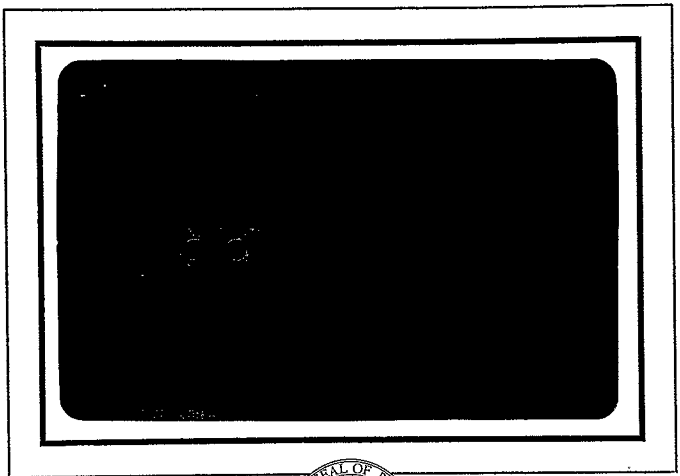

DEPARTMENT OF

SPACE SCIENCE

RICE UNIVERSITY

HOUSTON, TEXAS

CR 108651

Final Report

on

ELECTRIC FIELD METER INVESTIGATION

(NASA Contract NAS 9-7738)

23 February, 1968 to 31 July, 1970

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ACKNOWLEDGMENTS

The authors are greatly indebted to technicians Paul Monroe and Dan Boone and the others of the staff of the Space Science Facilities who contributed to this project; especially the staff of the machine shop.

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1.0 Introduction

1.1 History

The contract for development of the lunar electric field meter came about as the result of a proposal by Anderson and Manka submitted to NASA in November, 1965, to build a field meter for the ALSEP experiment package based on the deflection of an electron beam. At this time a feasibility model was operational at MSC utilizing a cathode-ray electron gun and had demonstrated the feasibility of this method for measuring electric fields down to 0.5 volt/meter. The proposal was modified to include the latest information on the feasibility model and re-submitted in October of 1966. It was the opinion of the evaluation board that the feasibility of the instrument had not been demonstrated and that further development work was called for. A contract was awarded Rice University in February of 1968 to develop a better electron gun. Simultaneously an effort was begun at NASA/MSC to develop the feedback electronics and the target.

1.2 Scientific Specifications

Scientific evaluations performed prior to and during the course of the feasibility study developed the following scientific criteria for the lunar electric field meter:

1.2.1 Instrument Configuration

The instrument shall consist of two antiparallel beams.

1.2.2 <u>Beam Length</u>

The beam length shall be as large as is possible but at least ½ meter.

1.2.3 <u>Beam Height</u>

The two beams will be placed parallel to the ground at a height of approximately ten centimeters.

1.2.4 <u>Beam Separation</u>

The beams will be separated by a distance of approximately ten centimeters.

1.2.5 <u>Beam Energy</u>

The beam energy will be capable of being varied from 100 volts to 1600 volts.

1.2.6 <u>Beam Current</u>

The electron beam currents will be less than $1(10^{-7})$ amperes and greater than $4(10^{-9})$ amperes.

1.2.7 <u>Surface Conditions</u>

The design of the instrument will be such as to allow the minimum of shadowing of the lunar surface below and one-half meter to either side of the electron beams.

1.2.8 <u>Electric Field Range</u>

The Electric Field Meter will measure fields from ± 100 volts/meter to ± .01 volts per meter.

1.2.9 <u>Electric Field Resolution</u>

The measurement of the electric field will be made with an uncertainty of ± .001 volts/meter or one per cent of the measurement, whichever is larger when in the presence

of the worst case magnetic field and mechanical-electrical offsets.

1.2.10 Magnetic Field

The E-field meter will measure to the required accuracy when in the presence of magnetic fields as large as $1(10^{-3})$ gauss.

1.2.11 Lunar Latitude

The E-field meter will be designed to operate at lunar latitudes within thirty degrees of the plane of the ecliptic.

1.2.12 Operational Period

The E-field meter will operate without degradation for at least one lunar year.

1.2.13 Frequency Response

The E-field meter will have a flat frequency response, within the limits of accuracy given above, from D.C. to ten Hertz.

1.3 Applicable Documents

1.3.1 Rice University

1.3.1.1 Proposal: To Build a Lunar Surface Electric Field Detector for the Apollo Lunar Surface Experiments Package, H. R. Anderson, R. H. Manka, November, 1965. NASA #44-006-(050).

1.3.1.2 Progress Report: R. H. Manka, February, 1968.

1.3.1.3 Statement of Work: NASA Contract NAS 9-7738,Electric Field Detector Development, February, 1968.

1.3.1.4 Progress Reports: Contract NAS 9-7738, January 1968 through August 1970.

1.3.1.5 Proposal: Lunar Electric Field Detector, H. R. Anderson, November, 1969.

1.3.1.6 Proposal: "An Instrumental Prototype Lunar Electric Field Detector", H. R. Anderson, August, 1970.

1.3.2 NASA/MSC-Lockheed

1.3.2.1 Report: Electron-Beam Electric-Field Meter Feasibility Report, LEC Document No. 644D.41.01.

1.3.2.2 Report: First Addendum, LEC Document No. 644.41.13.

1.3.2.3 Report: Electron-Beam Electric-Field Meter Final Report; LEC Document No. 644.41.54.

1.3.3 Analog Technology Corporation

A Proposal for a Lunar Electric Field Detector, ATC Proposal No. 69-255.

1.3.4 Bendix: Aerospace Systems Division

Preliminary Proposal for Design and Development of an Electric Field Detector, Proposal 1969-555-1.

1.3.5 Time-Zero Corporation

Electric Fields Detector, Proposal 2570.

2.0 Test Facility

Two test rigs have been built and utilized at Rice University to operate versions of the various electron guns and to determine their characteristics. The original chamber was designed for long-term stability runs and to operate continuously with little or no attention. When it became apparent that electron gun development would require a fast cycling system, a new chamber was designed and constructed utilizing a diffusion pump and the internal parts of the preceding chamber; with which known electric-fields may be produced. Shielding is used to drop the magnetic field to the $4(10^{-2})$ gauss level.

The test electronics include a DVM, an X-Y recorder, an ion gauge controller, a constant current filament supply, high voltage supplies, precision low voltage supplies for the E-field plates and the electron gun deflection plates, and a low voltage power supply for the feedback amplifier electronics. Switching panels are provided where required to allow fast measurement of parameters and quick variation of test conditions.

3.0 Electron Guns

The original feasibility study done prior to the award of this contract indicated that the best cathode ray tube electron guns used (2AP1) would not produce small enough beam diameters over the length of beam desired.

A different focusing gun was obtained by MSC from the National Bureau of Standards which was

designed especially for critical applications. This gun was used in most of the feasibility work carried out at MSC.

Immediately after the contract award, Rice University sent out an RFP for a gun, built especially for this application, in which beam stability was the primary consideration. General Electric was selected as the subcontractor. The first model of this gun was delivered in June, 1968.

An attempt to produce a gun design more suitable for reduction in size, weight, and power resulted in a gun design based on the Pierce model of concentric spheres. A model of this gun was first tested in December, 1969.

Test results were inconclusive until a version was tested in June, 1970 which followed the theoretical model more closely than previous Pierce-type designs. Tests on this new design showed characteristics suitable in almost every parameter as an electron gun for the E-Field meter.

A new model gun was designed and constructed in an attempt to reduce the size and weight to those compatible with a flight package while retaining the electrode configuration of the best Pierce gun. This gun has become known as the "instrumental prototype" and is considered a preliminary design to the flight configuration

3.1 <u>Specifications of the Electron Gun</u>

The following specifications were used in the RFP resulting in the award of the subcontract to

General Electric.

3.1.1 Beam Current: 10^{-7} to 10^{-9} amperes

3.1.2 Acceleration Potential: 50 to 10^3 volts, variable to one of ~5 preset voltages.

3.1.3 Beam Length: 0.5 to 1.0 meters, fixed.

3.1.4 Spot Size at Target: Less than 3mm diameter. Distribution of current density over the spot should be constant, and reproducible at each accelerating potential.

3.1.5 Deflection Plates: Orthogonal pairs of deflection plates must correct for deflections of 0.02 to 20 cm.

3.1.6 Poisoning: Cathode must withstand repeated exposure to the atmosphere when cold, and to laboratory vacuums of 10^{-6}mm Hg while hot without degradation.

3.2 Characteristics of the NBS Electron Gun Reported by MSC

3.2.1 Beam Current: Nominally $2(10^{-8})$amperes at 225 volts accelerating potential.

3.2.2 Acceleration Potential: Usable range 100 volts to 500 volts.

3.2.3 Beam Length: Up to one meter.

3.2.4 Spot Size: Below one millimeter.

3.2.5 Stability: The NBS gun is a focusing type gun and has a relative magnification of x10 for a beam one meter long. Any mechanical movements of the elements is amplified by a factor of ten.

3.2.6 Conclusions: The lack of mechanical stability of the gun itself and the resulting magnification

of any movements due to the focusing design rendered the NBS gun unsuitable as a final electron source. The good performance for most of the other parameters over limited range and its ready availability made it useful as a laboratory electron source while design and testing of the other guns was underway.

3.3 Characteristics of the General Electric Electron Gun

A RFP was prepared to obtain an electron gun with a very slightly divergent output beam which would also meet the specifications presented in 3.1. The contract was placed with General Electric in April, 1968 and the first gun was delivered in July, 1968.

The gun was tested in an experimental set-up which provided a vertical electric field of uniform characteristics along the full length of the beam. Helmholtz coils were provided to vary the magnetic field along the beam and to buck out the residual magnetic field of the Earth if desired. The filament supply, the accelerating, field and deflection voltages were well regulated and stable. Vacuum pressure was normally below $5(10^{-7})$mm Hg.

A diagram of the elements of the General Electric gun is shown in Figure 1-1. All gun elements except the cathode are well supported and should be stable mechanically. Some care is needed in assembly to insure proper alignment.

A negative accelerating potential was applied to the cathode. The grid could be varied plus or minus ten volts with respect to the filament-cathode assembly. The anode was at ground potential. The total current flow from the cathode to anode was measured and called the emission current, I_E. Voltages applied to the deflection plates were balanced with respect to ground.

The electron beam current, I_o, was collected at a four sector Faraday cup target provided by MSC. The current from each segment was fed to separate picoammeters when feedback amplifiers were not used.

3.3.1 Deflection Sensitivity

The deflection sensitivity of the gun was calibrated in terms of beam movement at the target and corresponding voltages required to center the beam at the target. To obtain the movement in centimeters at the target, the value of deflection required to move the beam from the exterior side of one sector to the exterior side of the other sector is measured at the half-current points. This is compared with the known width of the target in centimeters to obtain the system constants.

Deflection sensitivity to the deflection plates is given in Figure 3.2 as volts/centimeter deflection per volt of accelerating potential. This value should be a constant and the values obtained at different accelerating voltages do agree closely.

3.3.2 Beam Centering Voltage Versus Beam Energy

The deflection in centimeters from the center of the target for several values of accelerating potential is shown plotted in Figure 3.3. The electrostatic field was zero in this case. The magnetic field was that of the earth but a magnetic shield of unknown quality surrounds the experiment and the actual value of field is unknown. It is realized that the offset and magnetic field will vary; this data was taken only to demonstrate the method of deriving the value of the magnetic field and vertical offset.

The experimental values were found to fit the curve; $y = 43.35\ E^{-\frac{1}{2}} + 0.326$cm. The value of magnetic field derived from this is $4.07(10^{-2})$ gauss or $4.07(10^{3})$ gamma.

Both the values of the magnetic field and the mechanical offset are quite reasonable and demonstrate the feasibility of deriving these values by varing the accelerating voltage.

3.3.3 Effect of $\vec{E}$ Field and $\vec{B}$ Field on Beam Profile

Beam profiles were taken with and without an electrostatic and magnetic field in order to try to resolve any beam spreading due to defocusing or a spread in beam energy. There were no apparent changes in beam diameter when $\vec{H}$ or $\vec{E}$ fields were applied.

3.3.4 Beam Current Versus Grid Voltage

It is felt that, to a large extent, the values and functions of certain parameters are determined primarily by the filament or cathode installed in the gun rather than by the gun itself. These parameters are the voltages and currents of the filament and the grid cathode assembly and the resulting functions; the beam current, I_o, and the emission current, I_E.

I_o is plotted versus grid to cathode voltage in Figure 3.4. The curves indicate a voltage of plus five volts would be a good standard value.

3.3.5 Beam Current Versus Acceleration Potential

A plot of I_o versus V_o is shown in Figures 3.5 and 3.6 with V_{GK} at +4.5 volts the emission is temperature limited; with V_{GK} equal to zero the emission is space charge limited.

It is to be noted that this gun does not provide adaquate output below V_o equal to 200 volts.

3.3.6 Beam and Emission Current Versus Filament Current

A plot is shown in Figure 3.7 of the variation in I_o and I_E with filament current at V_{GK}= 0 and E = 800 V.

The ratio of I_E to I_o varies with the activation procedure. The current procedure gives about 10 na for I_o when I_E is 25 μa, at E = 800 V and V_{GK}= 0. The filament current corresponding to $I_o = 1(10^{-8})$A is about 3.4 amps. The power to the filament at this current is 4.9 watts with the present configuration.

3.3.7 Beam Current Versus Pressure

It has been found that I_o and I_E vary with the pressure in the vacuum chamber. A plot of I_o with pressure is shown in Figure 3.8.

3.3.8 Beam Current Stability

Some short term stability runs were attempted to determine the drift in I_o at a constant filament current. It was found that over a period of two days the variation

in I_o was extreme. A plot of this run is shown in Figure 3.9. It is to be noted that stability did improve with time; it is possible that the beam stability would be acceptable after a one or two day "warm-up" if the filament was not changed.

3.3.9 Beam Diameters

A table of beam diameters is shown in Figure 3.10 for the General Electric gun, along with the parameters of the gun at each accelerating voltage. This is not the final gun configuration and power to the filament is somewhat higher than the last General Electric gun model. The beam diameter is below the three millimeter goal only at or above 400 volts.

3.3.10 LaB_6 Cathode

The LaB_6 cathode was found to tend to reduce its activity by a considerable amount after cold exposure to atmosphere or while operating in pressure higher than $5(10^{-7})$torr. Reactivation to the same output level could be accomplished by operation at a lower pressure [below $2(10^{-7})$torr] for about two days.

The design of the cathode mount in the General Electric gun is felt to be poor. It is subject to shorts to the grid and to misalignment. It does not lend itself to the power reduction needed by a flight gun.

3.3.11 Conclusions

Because of its large size, high power requirement and lack of beam current below 200 volts, the General Electric gun was rejected as suitable for development to a flight prototype.

3.4 Characteristics of the Flight Configuration Gun

The following characteristics were derived as a result of experience in the gun development and as a result of conclusions derived from the feasibility study.

3.4.1 Electron Gun

The electron gun to be used in the Lunar Electric Field Detector will utilize shadowing to form a slightly diverging beam of electrons. A minimum number of electrostatic lenses will be used, to minimize shifts in the optical axis due to variations in applied voltages or mechanical shifts in the optical axis. Deflection plates will be provided to control the beam in two orthogonal axes. The gun will be of the minimum weight, size, and power consumption which will accomplish the required objectives.

3.4.2 Diameter

Less than 0.8 in (2cm)

3.4.3 Length

Less than 4.3 in (11cm)

3.4.4 Weight

Less than 5.0 oz (140gms) per gun

3.4.5 Accelerating Voltage

100 volts to 1.6 kilovolts

3.4.6 Power Consumption

Less than 1.5 watts per gun

3.4.7 Gun Constant, K_1

The gun will have a value of 2.5.

3.4.8 Beam Energy

The required beam energies are 100 V, 200 V, 400 V, 800 V, and 1600 V.

3.4.9 Beam Current

The design value of beam current will be $2(10^{-8})$ amperes. The range of beam current will be from $4(10^{-9})$ to $1(10^{-7})$ amperes.

3.4.10 Beam Diameter

The beam diameter one meter from the gun will be less than 3mm.

3.4.11 Beam Axial Stability

The design of the gun will be such that there will be minimum variation in the electron optical axis, measurable by the field detector system, when the beam energy is stepped or when the ambient operating temperature is varied over the operational temperature range.

3.4.12 Beam Energy Versus Deflection

The deflection voltages will be applied so that there is no change in axial beam energy with deflection potential.

3.4.13 Lifetime

The cathode material and the heater material and design will be such that the

operational life expectancy of the cathode is considerably better than one year, under operational conditions.

3.4.14 Cathode Poisoning

The gun will always be operated under a pressure of less than $5(10^{-7})$ torr. No materials will be used in the construction of the gun which will evolve products which decrease the cathode activity. A cathode will be used which will not suffer a reduction in activity due to exposure to air, when cold, after one activation and use in a vacuum.

3.4.15 Shielding

A grounded shield will be included as an integral part of the gun, which will prevent radiation of stray electrons.

3.4.16 Plating and Coating

Exterior surfaces may be plated or coated as required for thermal control, electrical conductivity or for corrosion prevention. Interior surfaces will be bare metal or ceramic.

3.4.17 Materials

All gun parts subject to electron bombardment or intense heat will be made from molybdenum. All metal parts subject to high temperatures will be made of molybdenum. All other metal parts will be made from non-magnetic stainless steel. All internal and external wiring will be made with multi-strand nickel wire, suitably insulated.

3.4.18 Accessability

The design of the gun mount and the wiring connections will be such as to allow rapid replacement of the electron gun. The internal design of the gun will be such that the cathode may be readily replaced.

3.5 Characteristics of the Pierce-Type Electron Gun

The Pierce gun tested at Rice is a straightforward development of the basic General Electric gun design modified to meet the above requirements. The immersion cathode was replaced by a planar Phillips cathode and the first collimating aperture was made much larger in size. The divergence of this aperture is corrected by the convergence of the curved accelerating region. The drift tube at ground potential and the existing shadowing aperture was retained.

The Pierce gun consists of two concentric spherical surfaces, with an exit hole in the sphere of smaller radius as shown in Figure 3.11. The electron lens formed by the two spherical surfaces has its' focal point at the common center of radius of the spherical surfaces. The focal length of the lens formed by exit hole is s/4, where s is the separation of the surfaces, or $r_c - r_a$. By proper choice of r_a/r_c the output beam can be made divergent or convergent. A parallel beam is predicted when r_a/r_c equals 0.707. A divergent beam is predicted for values of r_a/r_c greater than this;

convergent for r_a/r_c less than this.

Theoretically, the electron path is independent of V_o. The diode current is, however, proportional to $V_o^{3/2}$ if the cathode is operating in the space charge region. It is hoped that a fairly large percentage of the electrons produced would be utilized in the final output beam with this gun. This would require fairly large apertures and thus a highly collimated beam. If a large percentage of the electrons produced are utilized, the cathode may be operated in the saturated region and the beam current should be independent of V_o. Operation at this low emission level would permit a low cathode temperature and thus a much lower power consumption.

The design of the Pierce elements permits the utilization of a large portion of the emission of a larger cathode, the standard Phillips dispenser type. The lower work function of this cathode permits a lower operating temperature and thus a lower power input to the heater for the same output.

3.5.1 <u>Large-Scale Gun with Standard Phillips Cathode</u>

A gun based on the Pierce generating element with a standard Phillips cathode, was designed to fit in the frame of the General Electric gun, utilizing the drift tube, shadowing element and deflection plates of the General Electric gun. The

following parameters were used in this gun design

$R_c = 1.000$ inch

$R_a = 0.700$ inch

$d_c = 0.187$ inch

$d_a = 0.030$ inch

$d_s = 0.015$ inch

drift space length $= 2.000$ inch

A typical performance data set is shown in Figure 3.12. It is shown here that the electron beam's diameter does not change with beam current.

3.5.2 Effect of Anode Hole Diameter

Comparing the tables taken with an anode hole diameter of 0.100 inch to those taken with an anode hole of 0.030 inch in diameter it appears that the smaller size hole has less variation of beam diameter with changes in V_o. This is presumably the result of the smaller effect on the curved first lens. Due to the improvement in data and the larger number of anode assemblies with the smaller diameter hole this size was used for the remainder of the preliminary investigation of the Pierce gun. There seems to be little effect on electron efficiency when varying the anode hole, though, of course, there must be a

lower limit where it becomes significant.

3.5.3 Effect of Spacing, S

A set of data taken with a Pierce gun with v_c equal to one inch, v_a equals 0.68 inch, d_A equals 0.030 inch, and d_s equals 0.015 inch showed little effect from varying S from 0.015 below its ideal value (0.32 inch) to 0.015 above that value. Results were only fairly consistent and revealed that the smaller spacing produces a smaller diameter beam at v_o equal to 100 volts. The data at higher values of v_o showed a negligible or inconsistent result.

3.5.4 Smaller Size Pierce Gun

A smaller size gun was constructed and tested with R_c equal to 0.50 inch, R_a equals 0.34 inch, d_A equals 0.030 inch, d_s equals 0.015 and S its nominal value of 0.16 inch with the standard Phillips cathode.

The results of the tests on this gun are shown in Figure 3.13. The beam diameters are comparable with the larger guns, as are most other parameters. The power required to produce this beam showed little or no improvement, indicating that heat losses are primarily conductive rather than radiative. Subsequent testing was concentrated on the smaller guns, for reasons of physical compactness, and due to the fact that I_o shows less variation due to V_o.

3.5.5 Reduced Size Gun with Cupped Cathode

The scaled gun described above was subsequently fitted with a standard size, type B impregnated Phillips cathode with the emitting surface machined to a concave radius of 0.50 inch to match the beam forming surface adjacent to the actual cathode. The results are shown in Figure 3.14 and may be directly compared with the planar cathode surface installed in the gun shown in Figure 3.13. This shows a reduction in size of the beam diameter, D, and a reduced variation of I_o and D with V_o in comparison with earlier guns. With the exception of cathode power it is suitable for an instrumental prototype. Subsequent reduction in the cathode power as the cathode was outgassed in vacuo indicated considerable poisoning from the machining operation.

3.5.6 Beam Current Stability

After proper activation and operation in a good vacuum at a constant power setting the Phillips cathode provides a stable beam current; however, the time constant for changes in heater current is quite long. For this reason it was decided to operate the Pierce gun at a constant power setting for all values of V_o. The beam current will then vary with V_o but so long as the range of currents is limited the electronics can be designed to account for this.

3.5.7 Stability of the Loop Gain

An important parameter in the loop gain is the factor $I_o/V_o d$. If this factor is constant the loop gain will be constant. This factor (times 10^8) is calculated for the two two gun configurations shown in Figures 3.13 and 3.14. Had I_o and d been constant, this parameter would have varied by a factor of 16:1 over the range of accelerating voltages. It is desirable to have this function vary as little as possible.

3.5.8 Heater Power

A table of the characteristics of one Pierce gun is shown in Figure 3.15. This gun had been operated in vacuum and brought up to vacuum several times prior to this data being taken. The power required to produce a beam of around $5(10^{-8})$ amperes on the first activation was 1.2 watts. This is below the goal of 1.5 watts.

3.5.9 Conclusions

As all the various goals desired in the flight configuration gun except beam diameter at 100 volts and size and weight had been obtained in one form or another of the Pierce gun at some time in the test program, it was felt that the Pierce configuration would be satisfactory as a flight configuration. Additional development work would be carried out as part of the design and testing of an instrumental prototype

which would satisfy all desired parameters including size and weight, but would not necessarily be identical to the flight gun.

The primary advantage of the Pierce configuration is that only one voltage, the accelerating potential, is placed on the gun besides the heater power. In addition the configuration lends itself to efficient operation.

3.6 Instrumental Prototype Gun

An electron gun utilizing the Pierce type electron beam generator and the cupped standard Phillips cathode has been designed. This design will satisfy physically the parameters chosen for the flight gun. The Pierce gun design parameters will be capable of being modified at a later time from those chosen for the first model, if required. The first model has the same gun parameters as the gun described in Figure 3.15. These deviate from the acceptable only at V_o equal to 100 volts.

The gun specifications deemed suitable for a flight instrument are:

Beam current I_o, $4(10^{-9}) < I_o < 1(10^{-7})$ amps

Beam diameter < 4mm

Accelerating voltages from 100 volts to 1600 volts

Gun diameter < 0.80 inch

Gun length < 4.3 inches

Gun weight $\cong 3.5$ oz

Gun constant equal to 2.0

Gun power < 1.5 watts per gun

Gun parameter I_o/V_oD nearly a constant.

A cut-away section of this gun is shown in Figure 3.16. The drawing is 2x full size. The deflection plates are sections of a truncated cone epoxied to a ceramic support ring. A metal ring is used on the sides of the beam forming electrodes in order to prevent charge buildup. A standard Phillips cathode is machined to match the radius of the cathode beam former and is supported by 0.005 inch diameter Tantalum wire. Tungsten heater wires of 0.003 inch diameter were tried as a support but were too brittle.

This gun has not been tested fully but preliminary indications are that the Pierce elements are satisfactory, but that the cathode support will require redesign to reduce the power input.

4.0 Cathodes

4.1 Cathode Requirements

The cathode used in the flight configuration gun of the Lunar Electric Field Detector would have the following requirements placed upon it.

4.1.1 Low Power

Power less than 1.5 watts per gun

4.1.2 Stability

Short term variations in beam current less than 10% at a constant power input

4.1.3 Lifetime

Generation of an adequate beam at power levels less than 1.5 watts for a period of at least one year.

4.1.4 Poisoning

Operation on the lunar surface shall not be affected by previous operation in a vacuum and restoration to atmosphere prior to launch.

4.1.5 Reliability

The design of the cathode mount will not be affected by the various severe environments encountered prior to operation on the lunar surface.

4.1.6 Size

The design shall be accommodated in the instrumental prototype gun.

4.2 The LaB_6 Cathode

The requirements of lifetime and freedom from poisoning placed on the operational cathode eliminated the oxide cathode with its low power level. The pure metal and thoriated tungsten wire types were eliminated because of high power requirements. This left only the "dispenser" cathode types in which "poisoned" or lost cathode material is replinished from a resevoir of fresh material. The General Electric gun was furnished with such a cathode using LaB_6 as the emitting material.

The LaB_6 cathode was found to be suitable so far as freedom from poisoning is concerned if operated at pressures below $1(10^{-7})$ torr. The original design required about ten watts to produce a beam of $1(10^{-8})$ amperes at 800 volts. Subsequent redesign halved this figure but it was felt that the relatively high electron work function, 2.66 eV, the inefficiency of

the basic design and the poor reliability of the directly heated structure required the adoption of a different type of cathode.

4.3 The Phillips Cathode

4.3.1 Standard Phillips

The standard Phillips dispenser cathode was used in the NBS gun as supplied and was known to be able to survive several pump-down cycles. In this design the power consumption was above twelve watts. Use in the highly efficient Pierce element gun with a new mount reduced its power requirement below 1.5 watts for the type "B" impregnation.

4.3.2 Miniture Phillips Cathode

An attempt was made to substitute a very small (1.2mm diameter by 1mm length) solid body cathode of dispenser material supplied by Phillips in the General Electric gun for the LaB_6 cathode. The evaporation rate was so great that this cathode was rapidly depleted of active material and was abandoned.

4.3.3 Small Phillips Cathode

A Phillips cathode of the same configuration as the standard design but about half the length and 80% of the diameter in size was substituted in place of the standard unit in the Pierce element gun. No power reduction was noted. This would tend to indicate the primary power loss mode was conductive.

4.3.4 Cupped Standard Phillips Cathode

It was found necessary to machine the front face of the Phillips cathode used in the later models of the Pierce gun. This has reduced the output, the cathodes requiring several times more power for equivalent output. Presumably cathodes obtained from Phillips with a cupped face would not suffer from this problem.

4.4 Cold Cathode Electron Source

The cold cathode device obtained from the University of Arkansas, Department of Electronics and Instrumentation, was tested in the Rice facilities. A diagram of the layout of this device is shown in Figure 4.1. This device was described as producing a collimated beam of electrons with an initial diameter equal to the diameter of the base tubing. Beam currents were described as being on the order of one to ten microamps with an applied generator voltage of 300 volts and a generator current of one to ten milliamps.

This generator was placed in a standard General Electric gun as a replacement for the standard cathode. At 300 volts only twenty microamps of generator current were observed. Accidental increase of the generator voltage to 1300 volts caused catastrophic breakdown of the device, which no longer functioned. Prior to failure no outputs of either diode or beam currents were observed. The device was returned to the University of Arkansas of Little Rock and they agreed to investigate the usage of this source in the General Electric gun.

Construction of a gun similar to the General Electric gun at Little Rock indicated that the beam from the collimated of this source is in the form of a hollow tube. Apparently the cathode aperture was being ringed by the beam.

Work on this generator was set aside to investigate the same type of source, but in what is called the uncollimated mode of containing only the gap and no drift tube. Current outputs of the beam are about a decade greater than in the collimated mode at the same input currents. It has also been reported by the University of Arkansas that the spread of energy in electrons emitted is very small. Two sources have recently been received from the University of Arkansas It is proposed to utilize these sources much as a standard cathode in the Pierce gun and to place them as electron generators before a drift tube. The real question which must be investigated in the energy value and energy spread of the electrons from this source and the manner in which this affects the theoretical and practical performance of the various gun configurations. Secondary questions to be investigated are lifetime, stability, and power requirements. This work has not yet been done, but it is planned to complete it after the termination of the present contract.

5.0 Experimental Electronics

A general diagram of the basic feedback electronics is shown in Figure 5.1. The development of all electronics was placed in the hands of the Lockheed support group at

NASA/MSC. LEC Document No. 644D.41.54 contains diagrams, descriptions, error analyses, parts specifications, and performance results of prototype flight quality feedback amplifiers and an A-D converter and multiplexer. A diagram and preliminary specifications are included for a beam acquisition circuit, a stepping high voltage supply, a regulated filament supply and a test set. A block diagram of the electronics of the experiment is shown in Figure 5.2.

A system error analysis of a DC one-dimensional amplifier is included in the appendix of this report.

Also, preliminary analysis was performed on an AC type feedback system by the Lockheed group at MSC. Additional analysis are contained in the following proposals:

1) Analog Technology Corporation, Pasadena, California; ATC Proposal No. 69-255
2) Bendix: Aerospace Systems Divisions, Ann Arbor Michigan; Proposal 1969-555-1
3) Time Zero Corporation, Torrance, California; Proposal 2570

6.0 Mechanical Structure

The following is a description of a mechanical concept which would fit in the ALSEP Bay of the Lunar Module.

The Electric Field Detector is a self-contained unit consisting of electron guns and targets and their associated electronics housed in a folding case. The unit when erected is supported by three retractable legs and takes the form of a "C"-shaped structure, with the electron beams passing across the open leg of the unit. Figure 6.1 shows the deployed con-

figuration of the unit as well as the major components:

1) Electron Guns
2) Four Sector Targets
3) Target Electronics
4) Data Processing Electronics
5) Power Supplies and Thermal Control

The mechanical structure must provide location for the two electron guns and their corresponding targets and provide thermal control for the interior of the unit. The supporting structure also provides a case for the various electronic units. Rigidity of the supporting structure is important to maintain calibration. Folds were required in the structural assembly to reduce the external dimensions to those sompatible with the ALSEP package. These folds compromise the rigidity required and thus locating pins or pads with a locking device will be provided at each fold. Dust shields will be provided over the fold faces and over the apertures for the guns and targets. Thermal control will be provided by an external shell of insulation in conuunction with properly designed sunshades, heat sinks and radiators.

Figure 6.2 shows the major dimensions of the unit in the deployed configuration. The stored configuration is also shown in Figure 6.2 and the major steps in deployment are traced in Figure 6.3.

7.0 Results of the Feasibility Study at NASA/MSC.

Simultaneously with the development of the electron gun at Rice University the Manned Spacecraft Center, Space Physics Division of NASA, under the direction of Dr. J. McCoy, has been engaged in a complementary program to develop a working instrument. The work at MSC has been directed towards these areas:

1) Development of a target
2) Construction of an analog feedback system
3) Operation of a one-dimensional system with various applied fields to determine stability and verify the system equations.

Several types of targets have been tested, including sectors formed by evaporation of gold on insulating substrate, and sectors consisting of Faraday cups. Both Faraday cups and a suppressor are required to collect the entire beam and to retain the secondary electron created by impact. A sharp virtual beam splitter can be created by placing a repelling potential on a wire parallel to the boundary between sectors.

Investigations of guns and targets were carried out using an open loop system, with current from the sector measured by electrometer. A closed loop system was built using integrated circuits for the electrometer and feedback amplifier. With this, long-term runs were made to determine the stability of the system, reproducibility of the calibration from one run to the next, and linearity of response. The beam was run in a magnetically shielded vacuum chamber between parallel field plates with an externally applied potential across them. Linearity of response

to applied field was better than .1%, with the deviations from linearity being reproducible to within a much smaller uncertainty. A 4-week stability run with zero applied field showed that after initial warm-up, the output voltage, V_g, drifts no more than ± 0.004 volts or ± 0.01 millivolts per meter (until a shift after calibration). Much of this drift may be due to charging of the field plates.

Comparison of two calibrations of V_g versus applied field, made two months apart, shows a difference in measured V_g of less than 0.1% over the entire range of applied fields.

Measurements have also been made with various accelerating potentials and these successfully separated a magnetic deflection from mechanical offset. A small two beam system has been operated. Although the magnetic field is not the same at both beams, RMS fluctuations of 8.6 millivolts/meter and 0.23 gamma were seen. There appeared to be no long-term "charging" of electrodes after an initial warm-up drift.

The previous results were taken from a system which used an early model feedback amplifier designed to resolve ± 0.01 volts/meter and the NBS focusing gun.

8.0 Conclusions

The feasibility of utilizing an electron beam to measure an electric field has been demonstrated with a preliminary laboratory system at NASA/MSC to a resolution of ± 0.01 volts/meter and an accuracy of 0.1 percent.

The analysis of the system error sources shows that the quality of electronics required to obtain a resolution of 0.001 volts/meter over the required temperature range is well within the state of the art.

The electron gun development program has produced a laboratory prototype which is considered fully adequate in its characteristics (with the exception of size and weight) to perform in a flight system. An instrumental prototype based on this laboratory model has been designed in an effort to reduce the size and weight.

A cathode has been used in the laboratory model electron gun which will withstand at least one exposure to atmosphere after first activation and which will deliver an adequate beam at the low power levels required by the ALSEP package.

Operation of the preliminary system at NASA/MSC has demonstrated the feasibility of the technique of stepping the accelerating voltage to separate the deviations due to the $\vec{E}$-field, the $\vec{B}$-field and the mechanical-electrical offsets.

Preliminary designs of the mechanical structure have been analyzed at NASA/MSC and were considered to be adequate for a flight instrument which could fit in the ALSEP bay, be deployed on the lunar surface and perform the measurement to the required accuracy under the extremes of the lunar environment, and whose size, weight, and power requirements would not be excessive.

Theoretical calculations have been performed which indicate that the instrument in its present configuration will have a minimal effect on the lunar environment which it has been designed to measure.

A systems analysis of several AC-type feedback systems have been done at NASA/MSC and suggest an improvement in system performance at the cost of greater complexity when compared with the DC feedback system.

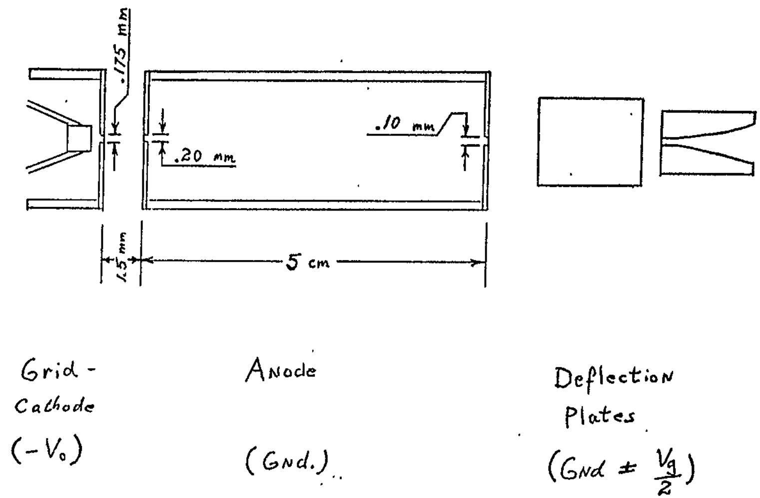
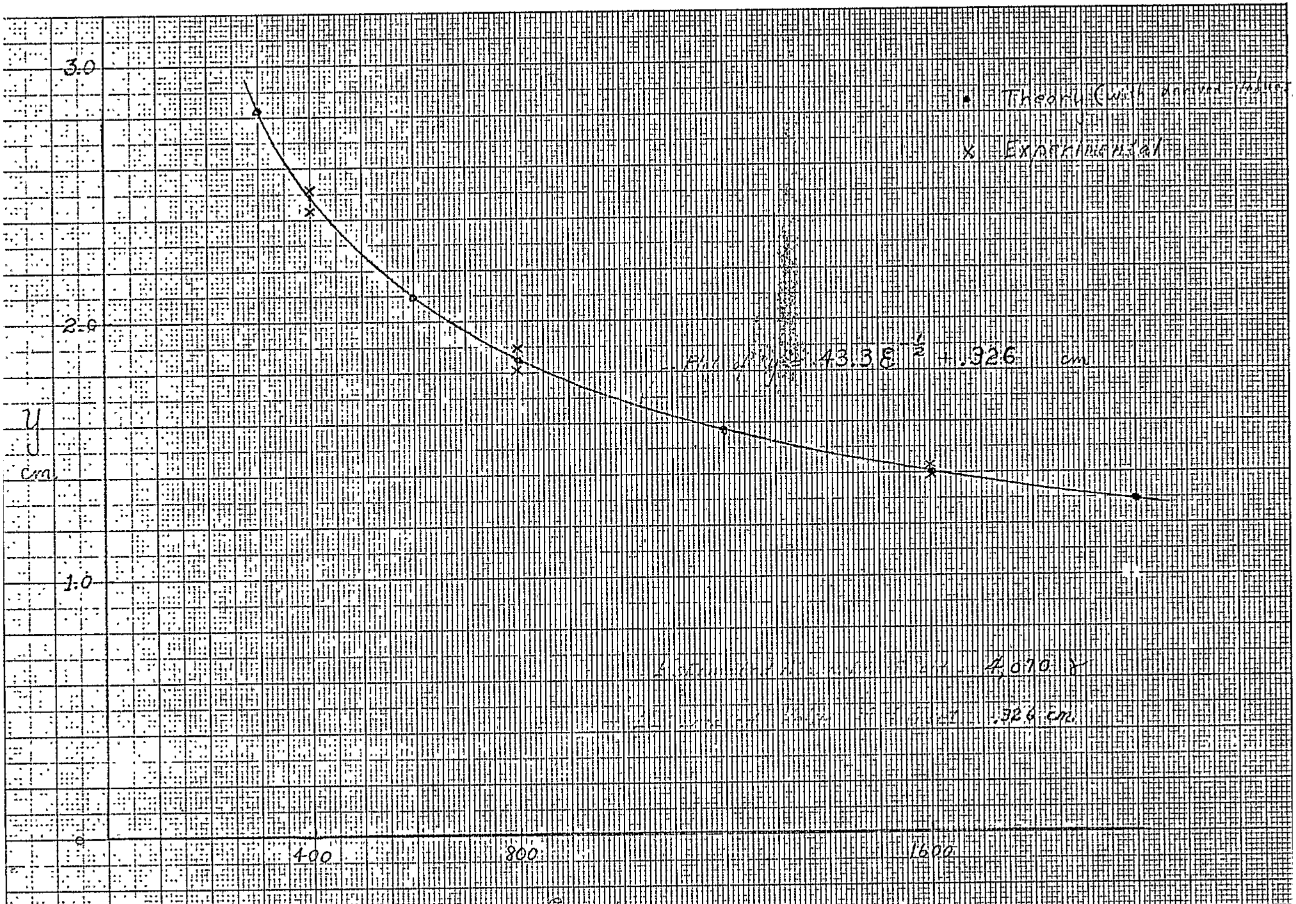

.175 mm
.20 mm
.10 mm
1.5 mm
5 cm
Grid - Cathode
$(-V_0)$
Anode
(Gnd.)
Deflection Plates
$(Gnd \pm \frac{V_g}{2})$

FIGURE 3-1

FIGURE 3.2

E	Vertical Sensitivity	Horizontal Sensitivity	
200 V	2.00 (10^{-3})	1.53 (10^{-3})	
400 V	1.99 (10^{-3})	1.48 (10^{-3})	$\frac{V/cm}{volt}$
800 V	1.91 (10^{-3})	1.49 (10^{-3})	
1600 V	1.89 (10^{-3})	1.45 (10^{-3})	
mean	1.95 (10^{-3})	1.45 (10^{-3})	$\frac{V/cm}{volt}$
max deviation	$\pm$.05 (2.5%) $-$.06 (3.0%)	$\pm$.04 (2.7%)	



3.0
2.0
1.0
0
y
cm
400
800
1600
E, volts
• Theory
× Experimental
43.3E + .326 cm
4,070
.326 cm.

Figure 3-3

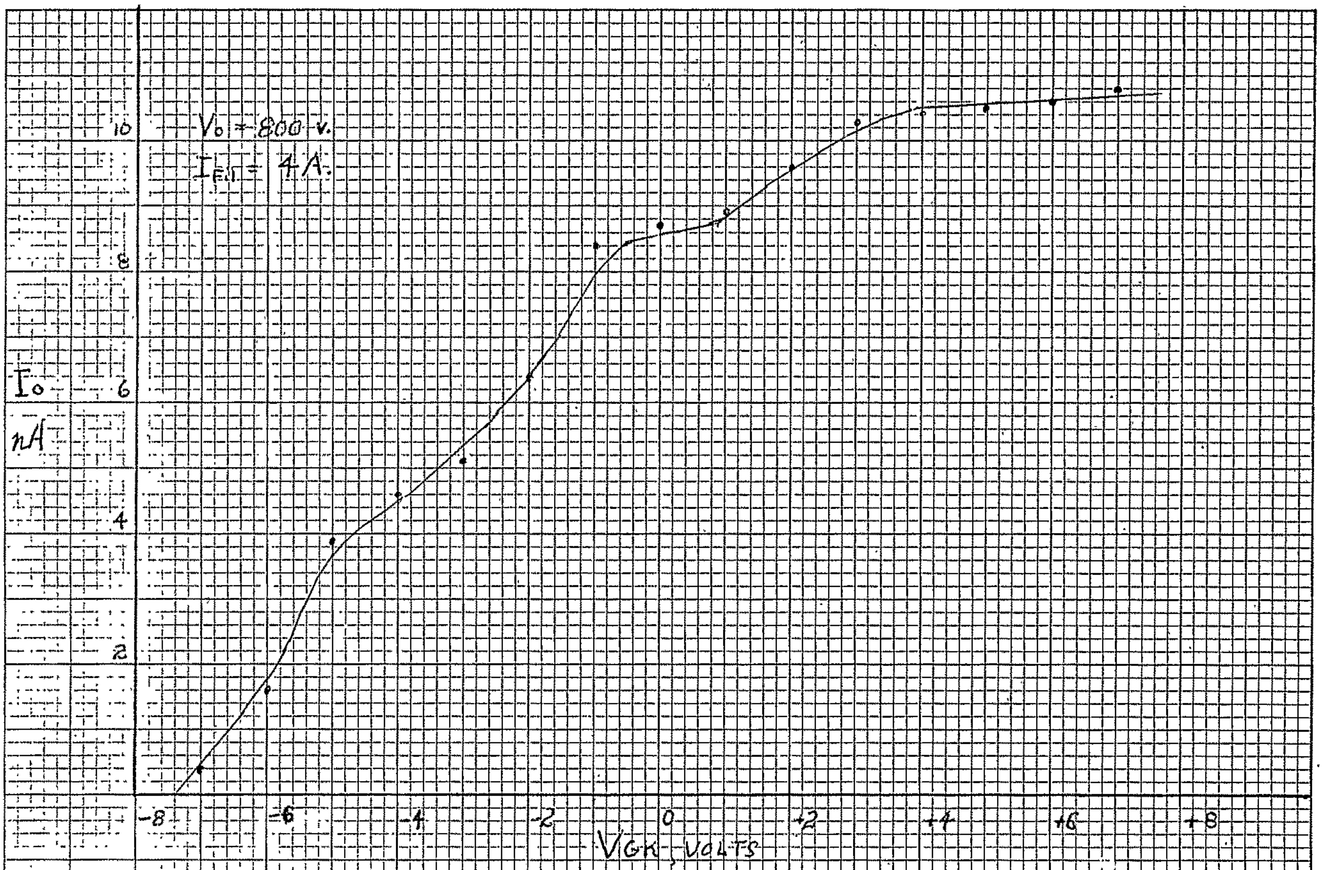


FIGURE 3-4

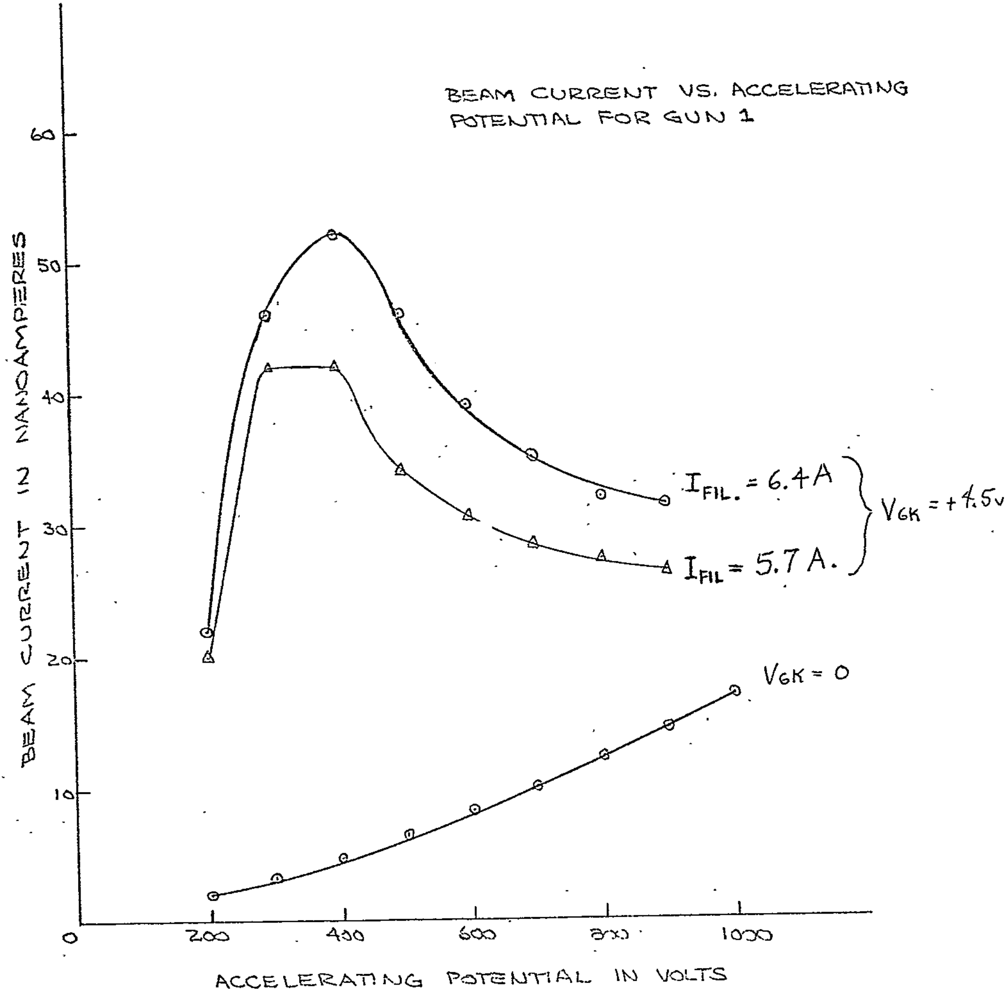
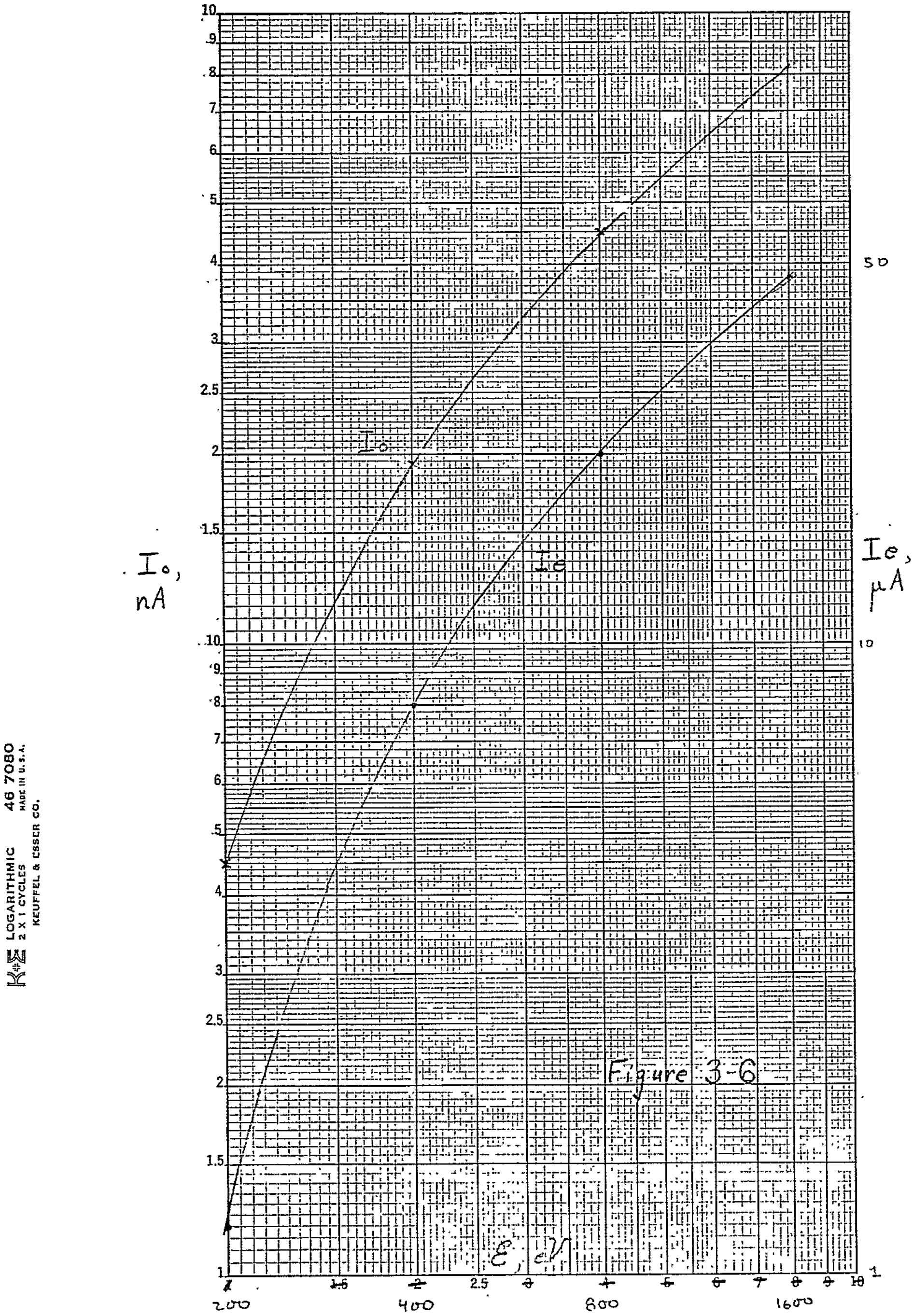
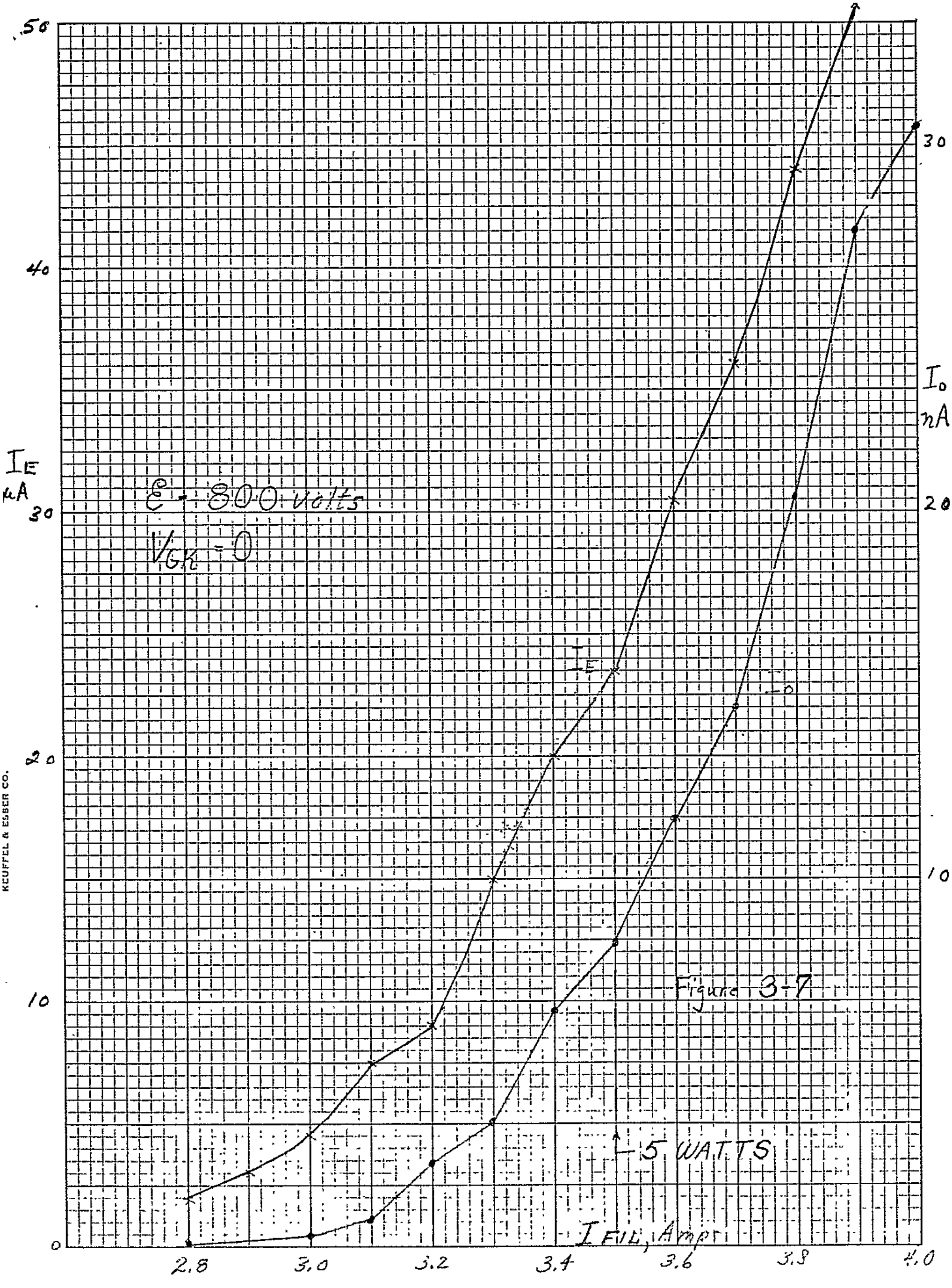

BEAM CURRENT VS. ACCELERATING POTENTIAL FOR GUN 1
BEAM CURRENT IN NANOAMPERES
ACCELERATING POTENTIAL IN VOLTS
0
10
20
30
40
50
60
200
400
600
800
1000
IFIL. = 6.4A
IFIL = 5.7 A.
VGK = +4.5v
VGK = 0

FIGURE 3-5

7-14-69



Io, nA
Ie, μA
Io
Ie
50
10
1
E, eV
200
400
800
1600
Figure 3-6
LOGARITHMIC 46 7080
2 X 1 CYCLES
KEUFFEL & ESSER CO.
MADE IN U.S.A.



.50
40
30
20
10
0
I_E
μA
$\mathcal{E}$ = 800 volts
V_{GK} = 0
I_E
I_0
I_0
nA
30
20
10
5 WATTS
I_{FIL}, Amps
2.8
3.0
3.2
3.4
3.6
3.8
4.0

Figure 3-7

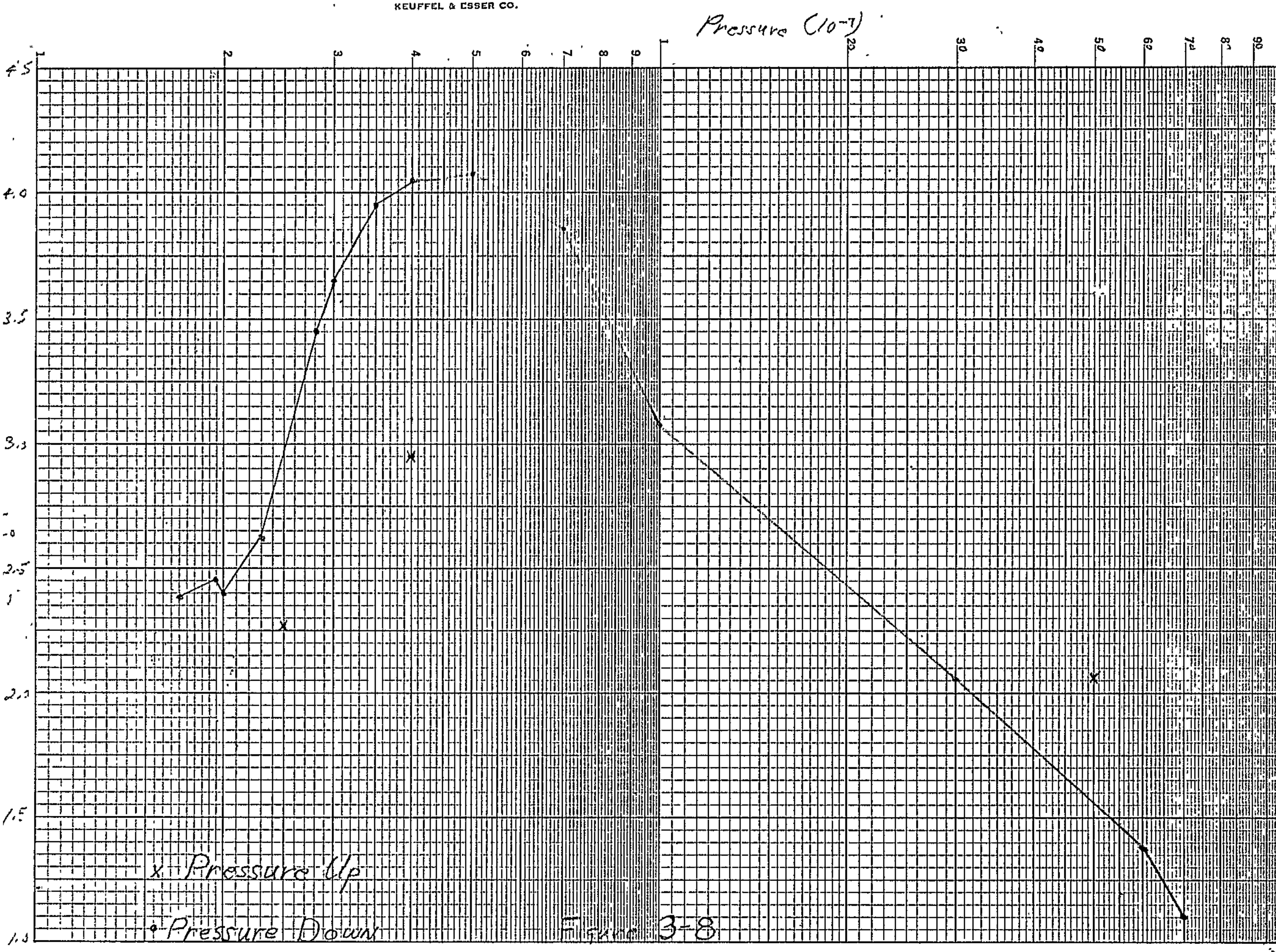

Pressure (10^{-7})
1
2
3
4
5
6
7
8
9
1
20
30
40
50
60
70
80
90
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
x Pressure Up
• Pressure Down

Figure 3-8

Figure 3-9

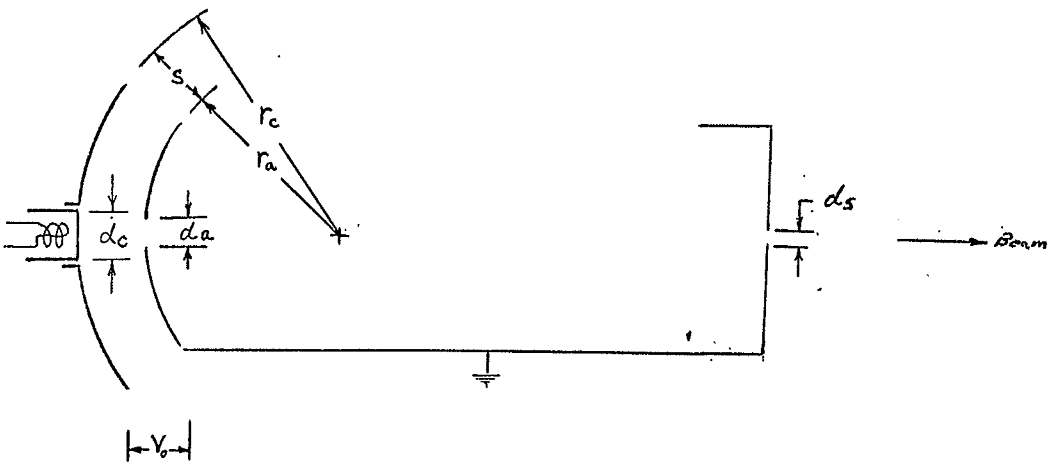
G.E. Gun #3 rebuilt

LaB_6 cathode - 6-27-69 Vgk = +4.5 V.

V_o	I_o (10^{-8}A) (nA)	I_E (μA)	D (mm)	Filament		
				A	V	P (watts)
100						
200	1.0	34	4.6	3.75	2.1	7.9
400	8.5	160	2.32	3.82	2.22	8.5
800	15.0	200	2.25	3.78	2.15	8.1
1600	3.2	320	2.3	3.8	2.2	8.4

Gun #1 obtained $1(10^{-8})$ A beam current at 800 volts at a filiment power of 4.9 watts. Diameters and emission currents are typical for these guns.

Figure 3.10



PIERCE GUN PARAMETERS

Figure 3.11

$R_a = .700 \quad d_a = .030 \quad d_s = .015$

V_o	I_o (10^{-8}A)	I_E (μA)	D (mm)	Filament A	Filament V	Filament P (watts)
100	.9	>50	7.2	.72	6.3	4.6
200	3.1	40.5	6.5	.7	6.2	4.3
400	.9 2.7 4.8 10.7	13.7 37.2 >50 >50	5.4 5.5 5.8 5.4	.66 .68 .7 .72	5.4 6.0 6.2 6.3	3.5 4.1 4.3 4.6
800	1.49	16.3	5.7	.66	5.4	3.5
1600	1.96	11.9	6.8	.62	5.1	3.17

$R_c = 1.000 \quad s = .302$

Figure 3.12

R_c = .500" d_a = .030" $V_{BS} = \frac{1}{2} V_o$

R_a = .340" d_s = .015"

$\frac{R_a}{R_c}$ = .680"   S = .160"

ΔS = .000   Flat-faced Standard Phillips Cathode, Type A

V_o	I_o (10^{-8}A)	I_E (μA)	D (mm)	$\frac{I_o(10^8)}{V_o D}$	Filament		
					A	V	P (watts)
100	.126	3.0	10.70	.106	.98	3.5	3.4
200	.616	3.5	4.53	.683	.98	3.5	3.4
400	1.240	4.2	2.90	1.080	.98	3.5	3.4
800	1.870	5.3	3.55	.658	.98	3.5	3.4
1600	2.350	8.0	3.70	.398	.98	3.5	3.4

FIGURE 3.13

$R_c = .500"$ $d_a = .030"$ $BS = \frac{1}{2} V_o$

$R_a = .340"$ $d_s = .015"$

$\frac{R_a}{R_c} = .680"$ $S = .160"$

$\Delta S = .000$

Standard Phillips Cathode, Type B, with the emitting surface machined to a radius of .5 inch.

V_o	I_o (10^{-8}A)	I_E (μA)	D (mm)	$\frac{I_o(10^8)}{V_o D}$	Filament		
					A	V	P (watts)
100	.71	20.0	4.30	1.65	.55	5.35	2.94*
200	1.37	23.3	3.25	2.12	.55	5.35	2.94*
400	1.32	27.0	2.28	1.29	.55	5.35	2.94*
800	1.02	30.8	2.59	.49	.55	5.35	2.94*
1600	.39	32.7	3.10	.08	.55	5.35	2.94*

FIGURE 3.14

* After two days of outgassing, the power required to produce 20 microamps of emission current at 100 volts dropped to 1.85 watts.

R_c = 1.00 d_a = .030

R_a = .68 d_s = .015

Δ_s = - .005

Flat Phillips Cathode, Type B

V_o	I_o $(10^{-8}A)$	I_E (μA)	D (mm)	$\frac{I_o(10^8)}{V_o D}$	Filament		
					A	V	P (watts)
100	.582	9.2	5.43	1.07	.45	3.65	1.64
200	1.031	11.0	4.67	1.10	.45	3.65	1.64
400	2.142	13.8	3.54	1.52	.45	3.65	1.64
800	4.486	18.4	3.72	1.50	.45	3.65	1.64
1600	9.152	24.2	3.57	1.6	.45	3.65	1.64

FIGURE 3.15

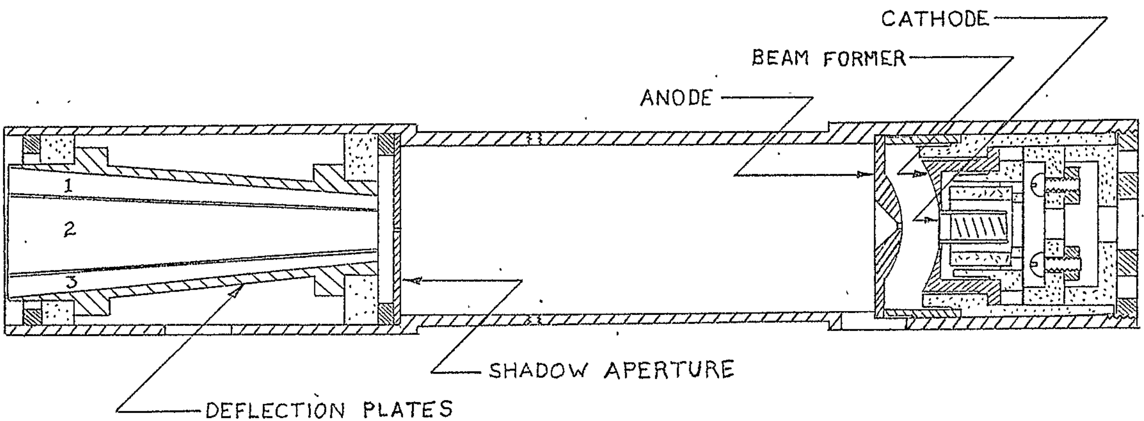
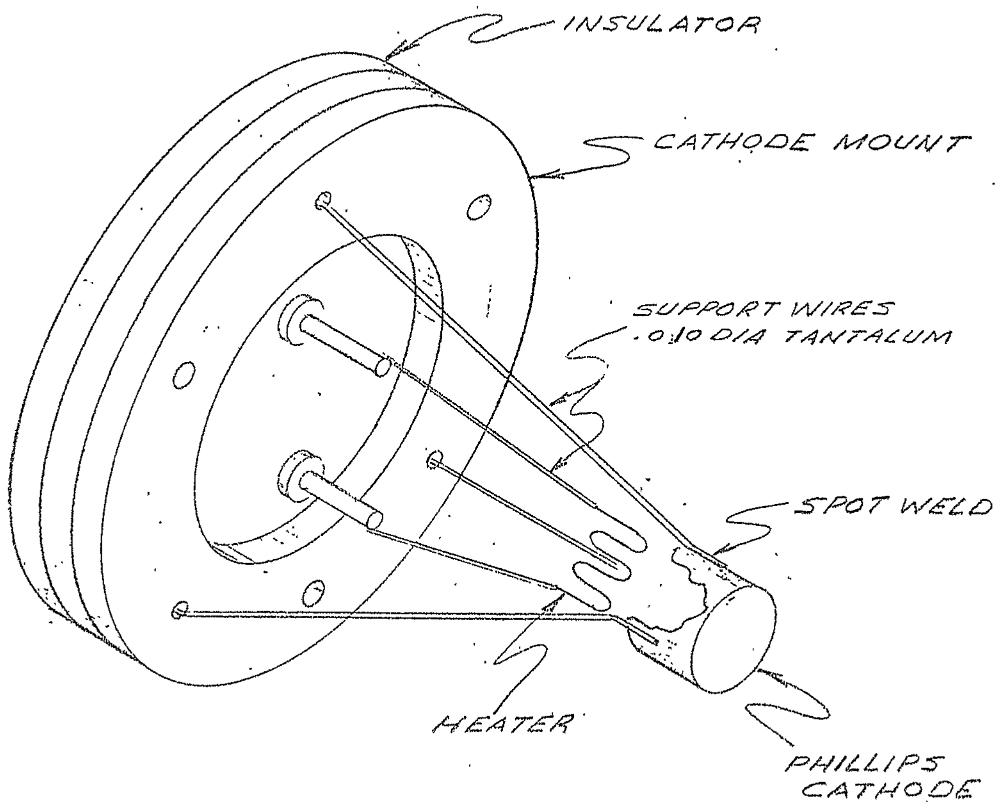

CATHODE
BEAM FORMER
ANODE
1
2
3
SHADOW APERTURE
DEFLECTION PLATES

FIGURE 3-16



PHILLIPS CATHODE MOUNT
Figure 4.1

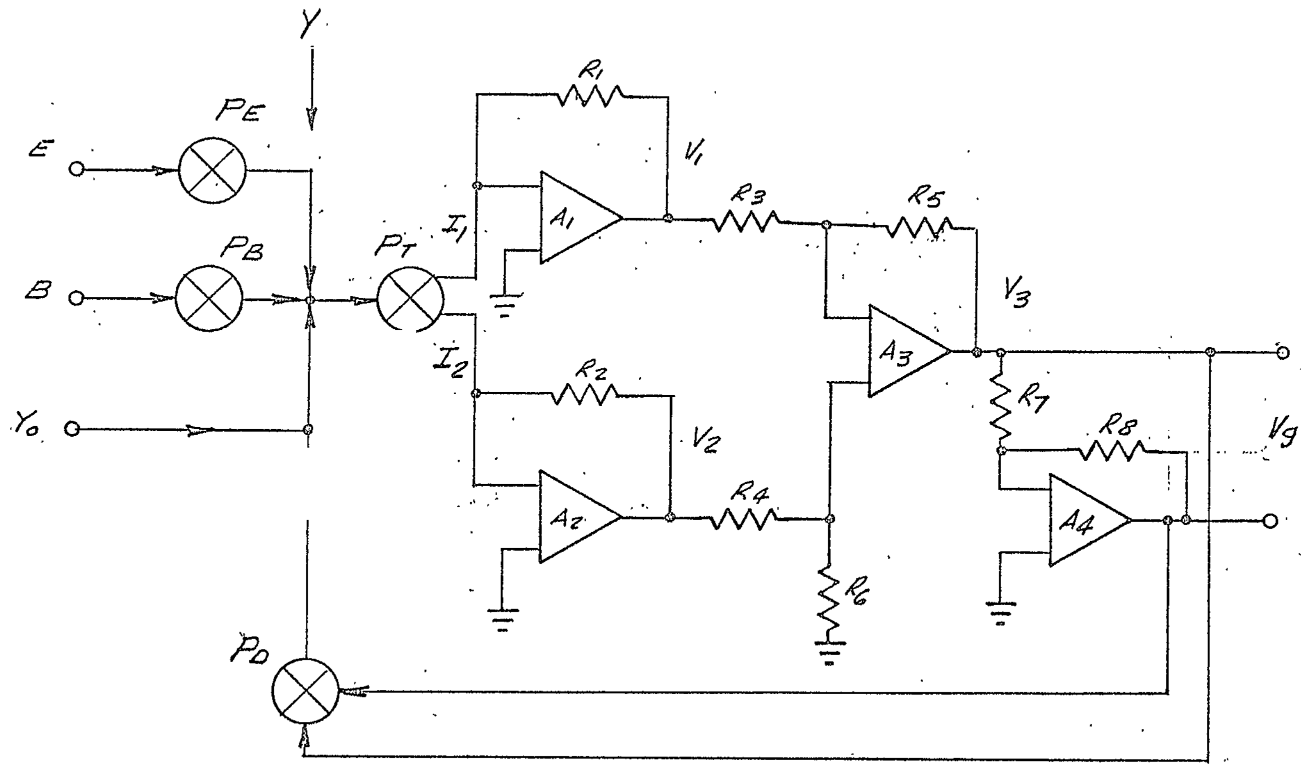


FIGURE 5-1

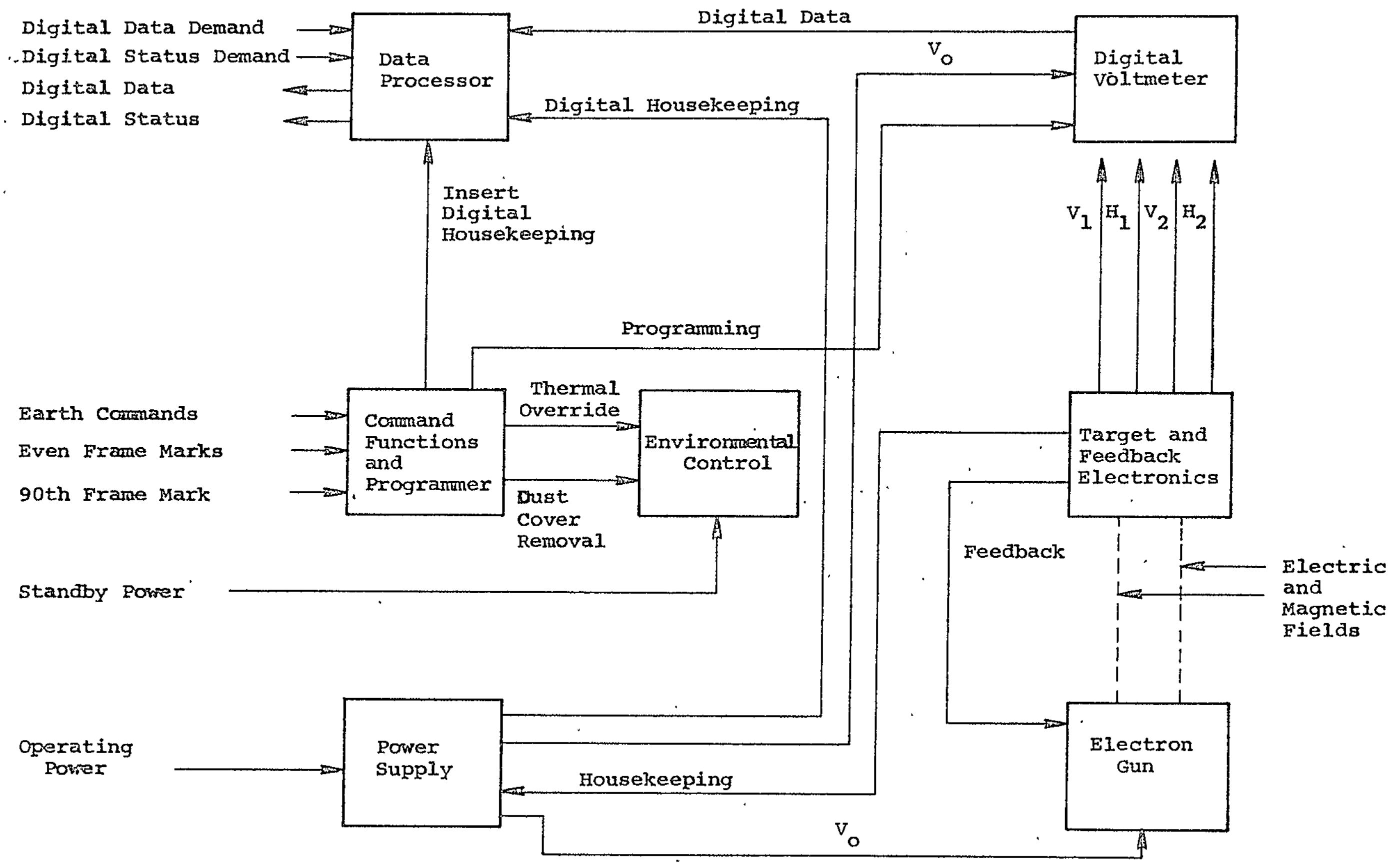
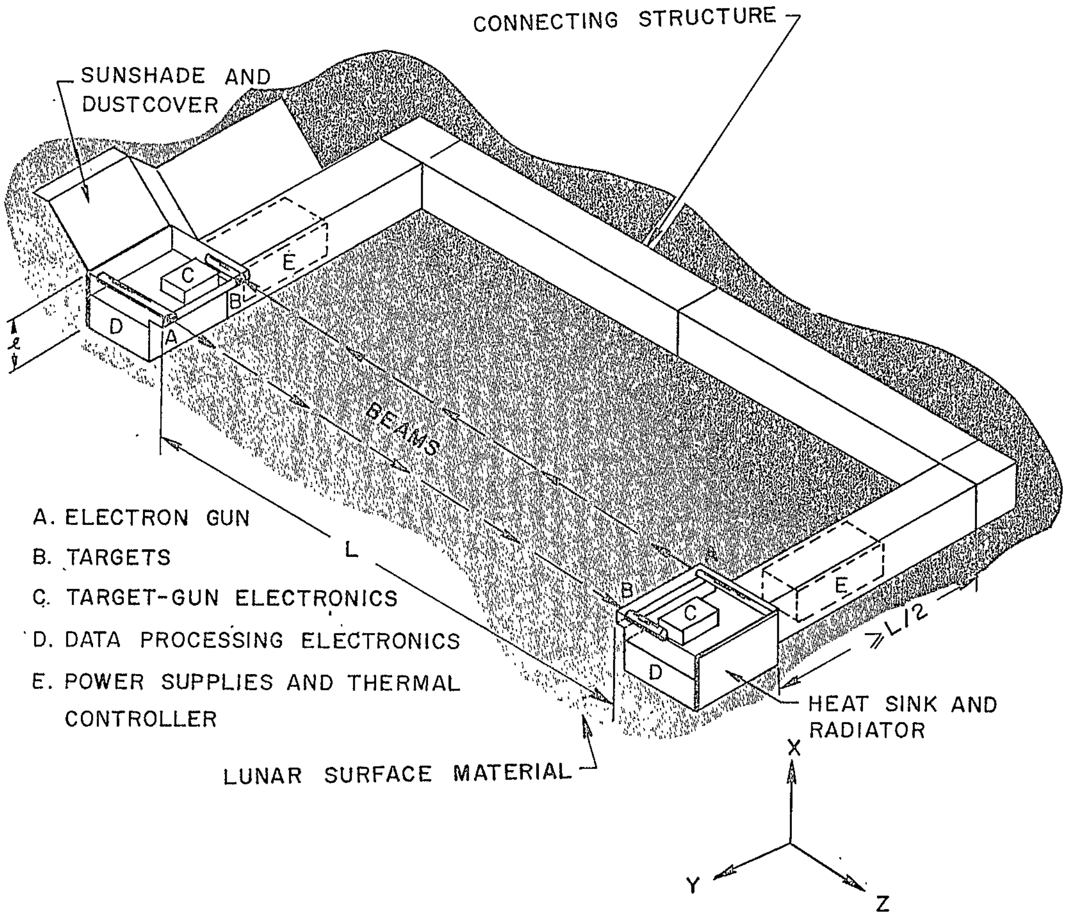
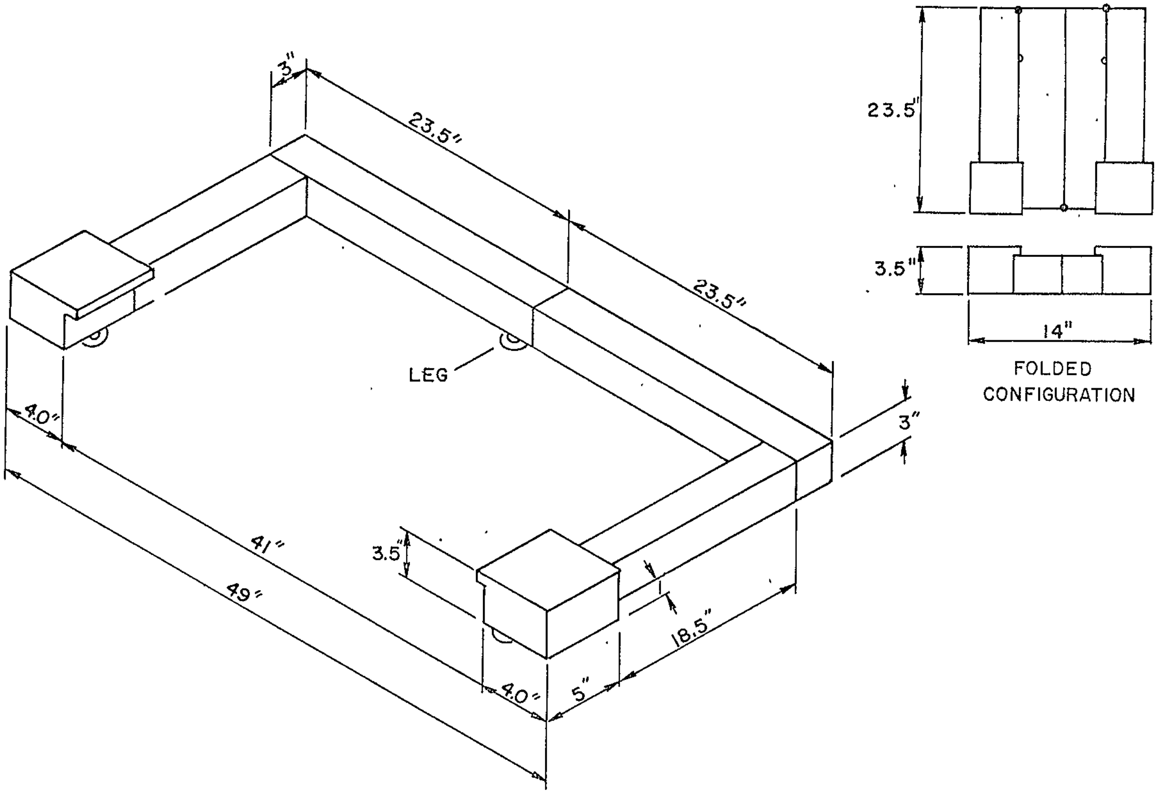

Digital Data Demand
Digital Status Demand
Digital Data
Digital Status
Data Processor
Digital Data
V_o
Digital Voltmeter
Digital Housekeeping
Insert Digital Housekeeping
V_1 H_1 V_2 H_2
Programming
Earth Commands
Even Frame Marks
90th Frame Mark
Command Functions and Programmer
Thermal Override
Environmental Control
Dust Cover Removal
Target and Feedback Electronics
Feedback
Electric and Magnetic Fields
Standby Power
Operating Power
Power Supply
Housekeeping
Electron Gun
V_o

Figure 5.2



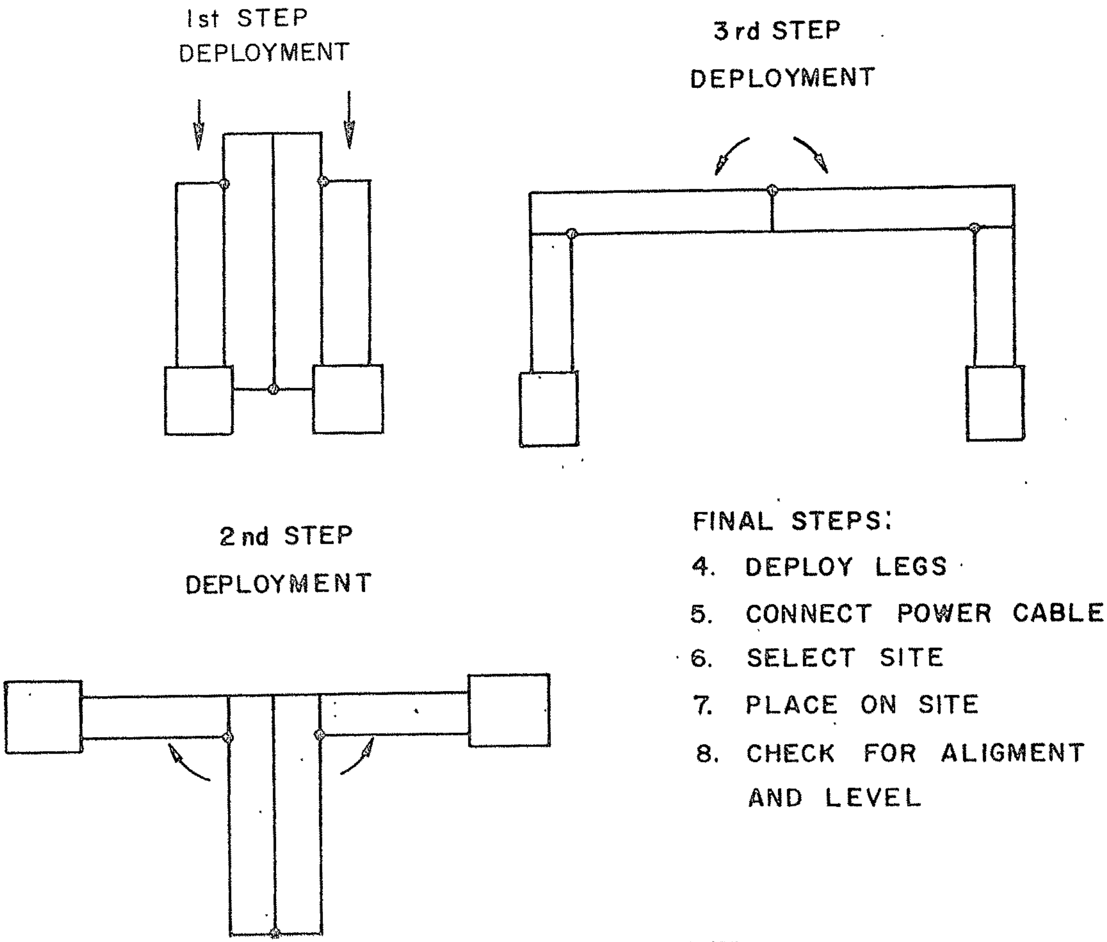
DEPLOYED CONFIGURATION

FIG. 6.1



DIMENSIONS OF DEPLOYED CONFIGURATION

FIG. 6.2



STEPS IN DEPLOYMENT

FIG. 6.3

APPENDIX

LEFD D.C. SYSTEM ANALYSIS

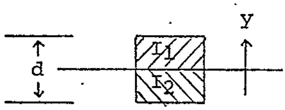
The transfer functions of the LEFD are (see Figure 5.1):

For E : $$y_E = \frac{L_E^2 E}{4 V_o}$$

For B : $$y_B = L_B^2 \sqrt{\frac{e}{8 m V_o}}\, B$$

For Vg: $$y(Vg) = -\frac{K_1 L_E Vg}{V_o}$$

The target transfer functions for a square beam and in one dimension are:



$$I_1 = \frac{I_o}{2} + \frac{y I_o d}{d^2}$$

$$I_2 = \frac{I_o}{2} - \frac{y I_o d}{d^2}$$

$$y + y_o + y(E) + y(B) + y(Vg) = 0$$

but $y(Vg)$ is a function of y.

Find: Vg

Assume: $Vg = 2\ V_3$

$$V_3 = \frac{(V_1 - V_2)}{2} \left(\frac{R_5}{R_3} + \frac{R_6}{R_4} \right) = (V_1 - V_2)G$$

or

$$Vg = (V_1 - V_2) \left(\frac{R_5}{R_3} + \frac{R_6}{R_4} \right)$$

$$V_1 = I_1 R_1$$

$$V_2 = I_2 R_2$$

from P_T ;

$$I_1 = \frac{I_o}{2} + \frac{yI_o}{d}$$

$$I_2 = \frac{I_o}{2} - \frac{yI_o}{d}$$

so:

$$Vg = \left[\left(\frac{I_o}{2} + \frac{yI_o}{d} \right) R_1 - \left(\frac{I_o}{2} - \frac{yI_o}{d} \right) R_2 \right] \left(\frac{R_5}{R_3} + \frac{R_6}{R_4} \right)$$

$$Vg = I_o \left[\left(\frac{R_1 - R_2}{2} \right) + \frac{y}{d} \left(R_1 + R_2 \right) \right] 2G$$

$$Vg = I_o G (R_1 - R_2) + \frac{2 I_o y (R_1 + R_2) G}{d} \tag{1}$$

$$y(Vg) = - \frac{K_1 L_E Vg}{V_o}$$

$$y_s = y_o + y(E) + y(B)$$

$$y + y_s + y(Vg) = 0$$

$$y + y_s - \frac{K_1 L_E Vg}{V_o} = 0$$

$$Vg = \frac{(y + y_s)(V_o)}{K_1 L_E} \tag{2}$$

Solve (1) for y

$$\frac{2 I_o y (R_1 + R_2) G}{d} = Vg - I_o G(R_1 - R_2)$$

$$y = \frac{dVg}{2 I_o (R_1 + R_2) G} - \frac{d(R_1 - R_2)}{2(R_1 + R_2)} \tag{3}$$

(3) into (2)

$$Vg = \frac{VgV_o d}{2 K_1 L_E I_o G(R_1 + R_2)} - \frac{V_o d(R_1 - R_2)}{2 K_1 L_E (R_1 + R_2)} + \frac{y_s(V_o)}{K_1 L_E}$$

$$Vg \left[1 - \frac{dV_o}{2K_1 L_E I_o G(R_1 + R_2)} \right] = \frac{y_s V_o}{K_1 L_E} - \frac{dV_o (R_1 - R_2)}{2K_1 L_E (R_1 + R_2)} \tag{4}$$

Evaluate: $$\frac{dV_o}{2K_1L_EI_oG(R_1+R_2)}$$

Let: $$H = \frac{2K_1L_EI_oG(R_1+R_2)}{dV_o}$$

$$H = \frac{2(1)(1)(2)(10^{-8})(10^2)(2)(10^8)}{10^{-3}(10^2)}$$

$$= 8(10^3) \gg 1$$

$$Vg = \frac{\dfrac{y_sV_o}{K_1L_E} - \dfrac{dV_o(R_1-R_2)}{2K_1L_E(R_1+R_2)}}{1-\dfrac{1}{H}}$$

$$\frac{dV_o(R_1-R_2)}{2K_1L_E(R_1+R_2)} = \frac{I_oG(R_1-R_2)}{H}$$

$$Vg = \frac{y_sV_o}{K_1L_E} - \frac{I_oG(R_1-R_2)}{H}$$

Evaluate: $\frac{I_o G(R_1-R_2)}{H}$

$$I_o = 2(10^{-8})$$

$$G = 10^2$$

$$R_1 - R_2 = (.01)(10^8)$$

$$H = 8(10^3)$$

$$\frac{I_o G(R_1-R_2)}{H} = \frac{2(10^{-8})(10^2)(10^{-2})(10^8)}{8(10^3)}$$

$$= \frac{(10^{-3})}{4}$$

$$= .25(10^{-3}) \text{ volts}$$

Assume tracking to five parts in 10,000.

$$\Delta V = .0125 \text{ mv}$$

$$\Delta E = .06 \frac{\text{mv}}{\text{m}}$$

Victoreen MOX resistors have been tested to track to better than five parts in 10,000 over a temperature range of 15°C with only a small effort at preselection. It is considered that only a small amount of effort would be needed to correct the amplifier electronics to this level over the entire temperature range by testing and substitution of parts. There is of course some question with respect to long-term stability of this tracking error.

Any drift in the amplifier may be related to an I_{OFFSET} drift, as defined in the systems equations.

$$Vg(I_{OFFSET}) = \frac{D}{2K_1L_E}\left(\frac{V_o}{I_o}\right) I_{OFF}$$

$$Vg(I_{OFF}) = \frac{I_{OFF}(AR)}{H}$$

If D and I_o do not vary with V_o , then any drifts in the amplifiers will show up as indistinguishable from a mechanical offset drift.

E-FIELD ERROR ANALYSIS

$$Vg = \alpha E + \beta\sqrt{V_o}\,B + \gamma V_o X_o$$

Given: α , β , γ ; find E , B , X_o from three equations of $Vg(V_o)$

Derive $\Delta E(\Delta Vg)$

$$\alpha E + \beta\sqrt{V_o^{\,1}}\,B + \gamma V_o^{\,1} X_o = Vg^1$$

$$\alpha E + \beta\sqrt{V_o^{\,2}}\,B + \gamma V_o^{\,2} X_o = Vg^2$$

$$\alpha E + \beta\sqrt{V_o^{\,3}}\,B + \gamma V_o^{\,3} X_o = Vg^3$$

Solve by Determinants:

$$E = \frac{1}{\alpha}\;\frac{\begin{vmatrix} Vg^1 & \sqrt{V_o^{\,1}} & V_o^{\,1} \\ Vg^2 & \sqrt{V_o^{\,2}} & V_o^{\,2} \\ Vg^3 & \sqrt{V_o^{\,3}} & V_o^{\,3} \end{vmatrix}}{\begin{vmatrix} 1 & \sqrt{V_o^{\,1}} & V_o^{\,1} \\ 1 & \sqrt{V_o^{\,2}} & V_o^{\,2} \\ 1 & \sqrt{V_o^{\,3}} & V_o^{\,3} \end{vmatrix}}$$

$$E = \frac{Vg^1|D_1| - Vg^2|D_2| + Vg^3|D_3|}{\alpha|D_4|}$$

where
$$|D_1| = \sqrt{V_o^2}\, V_o^3 - \sqrt{V_o^3}\, V_o^2$$

$$|D_2| = \sqrt{V_o^1}\, V_o^3 - \sqrt{V_o^3}\, V_o^1$$

$$|D_3| = \sqrt{V_o^1}\, V_o^2 - \sqrt{V_o^2}\, V_o^1$$

$$|D_4| = |D_1| - |D_2| + |D_3|$$

$$\frac{dE}{E} = \frac{dVg^1|D_1| - dVg^2|D_2| + dVg^3|D_3|}{Vg^1|D_1| - Vg^2|D_2| + Vg^3|D_3|}$$

If: $V_o^1 = 100$ volts

$V_o^2 = 400$ volts

$V_o^3 = 1600$ volts

$$|D_1| = 20\cdot1600 - 40\cdot400 = 1600$$

$$|D_2| = 10\cdot1600 - 40\cdot100 = 1200$$

$$|D_3| = 10\cdot400 - 20\cdot100 = 200$$

$$|D_4| = 600$$

$$<(dE)^2> = \frac{\sqrt{|D_1|^2 (dVg^1)^2 + |D_2|^2 (dVg^2)^2 + |D_3|^2 (dVg^3)^2}}{\alpha |D_4|}$$

$$<(dE^2)> = \frac{1}{24} \sqrt{256 (dVg^1)^2 + 144 (dVg^2)^2 + 4 (dVg^3)^2}$$

Assume:	$B = 100\ \gamma$		$L = 1$ meter
	$E = 100\ \frac{mv}{m}$		$h = 1.0$
	$X_o = .3$ mm		$H \gg 1$
	$V_o^1 = 100$ volts		
	$V_o^2 = 400$ volts		
	$V_o^3 = 1600$ volts		
Then	$Vg^1 = .6$ volts		
	$Vg^2 = .9$ volts		
	$Vg^3 = 1.8$ volts		

Examination of these equations shows that when B and/or X_o are non-zero, the accuracy with which Vg must be measured is greatest for E = 100mv/m . The above values therefore represent a worst case.

Assume the measurement is made to an uncertainty of .1% .

$$dVg^1 = .6(10^{-3})$$
$$= .6 \text{ mv}$$

$$dVg^2 = .9(10^{-3})$$
$$.9 \text{ mv}$$

$$dVg^3 = 1.8(10^{-3})$$
$$= 1.8 \text{ mv}$$

Then $$<(dE)^2> = \frac{(10^{-3})}{24}\sqrt{256(.36) + 144(.81) + 4(3.25)}$$

$$= \frac{(10^{-3})}{24}\sqrt{92.4 + 117 + 13}$$

$$= \frac{(10^{-3})}{24}\sqrt{222}$$

$$= \frac{14.8}{24}(10^{-3})$$

$$= .62(10^{-3}) \text{ volts/meter}$$

$$= .62 \text{ mv/m}$$

which is acceptable.

Proposal to Complete

AN INSTRUMENTAL PROTOTYPE

LUNAR ELECTRIC FIELD DETECTOR

Submitted to

National Aeronautics & Space Administration

Washington, D.C. 20546

Submitted by

Rice University

Houston, Texas 77001

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for F. E. Vandiver, Acting President
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Summary

Studies of a lunar electric field detector were begun in late 1965 at the Manned Spacecraft Center and Rice University. The instrument measures electric fields by the deflection of an electron beam. Advanced breadboard circuitry and a prototype electron gun have been built. Major components of the instrument have been operated at the two laboratories, but no complete instrument has been constructed. A flight proposal for Apollo XVII-XVIII was rejected because further development is needed before flight hardware is built.

We propose to incorporate the developed parts of the instrument into an instrumental prototype including mechanical structure, and to calibrate it. This could be converted into a flight prototype without major redesign. A sum of $75,547 is requested for use at Rice University from 1 January 1971 - 30 April 1972.

I. Introduction

We propose herein to carry the development of a lunar electric filed detector from its present state to a complete and calibrated instrumental prototype. The detector will measure the electric field just above the lunar surface which is generated in the plasma sheath surrounding the moon. The field must be measured throughout at least one lunar day, and the instrument is designed to operate for a year.

To do this the instrument is placed on the lunar surface and connected to its own power source and telemetry transmitter or to a central station such as an ALSEP. The instrument projects two horizontal, anti-parallel beams of electrons from two guns to corresponding targets spaced ~1 meter away. In this space the beams are unshielded and so deflect equally due to electric fields and oppositely due to magnetic fields. Each target is divided into four sectors and differences in current to opposite sector pairs are amplified and fed back to correcting deflection plates at each gun to keep the beams centered on the targets. The correcting deflection plate voltage is a measure of the deflection which would occur in the absence of the negative feedback. The electron accelerating voltage is stepped from ~100v to 1600v. From the resulting deflection of the two beams it is possible to measure the vertical and one horizontal component of electric fields from .01 to 100 v/m in the presence of magnetic fields from 0 to 100 gamma strength. The scientific significance of the measurement and a detailed description of the apparatus are given in the appendix, taken from a flight proposal written in November 1969.

The experiment was first proposed in November 1965 by H. R. Anderson of Rice University and R. H. Manka of NASA-MSC and a budget and schedule for development of a flight instrument were requested. Laboratory feasibility studies were started on the instrument some months later at MSC although the instrument had not been accepted for flight by NASA. In February 1968 Rice was awarded a contract by MSC for development of a special electron gun for the detector and the testing of the gun with circuits and targets to be developed and supplied by MSC.

Development proceeded satisfactorily and in November 1969 we submitted a new proposal to build flight instruments as part of the ALSEP on Apollos XVII and XVIII. The proposal has been rejected, and we understand that one objection to it was the development remaining on the instrument. As a result the work at MSC terminated on 30 June 1970, and Rice's contract with MSC terminates 31 August 1970. The status of the instrument as of this time is given in the next section.

We believe that with a relatively small amount of additional effort, the different parts of the instrument developed at the two laboratories can be brought together into a working, calibrated instrument. By the addition of non-critical subsystems, such as power supplies and data handling units, and by substitution of flight rated parts in the critical units already incorporated in this instrumental prototype, it can be upgraded to a prototype flight instrument.

II. Present State of Development

A. Analyses

A number of studies have been made to assure that the instrument will measure the field with the desired resolution of 0.001 v/m and absolute accuracy of at least 0.01 v/m. We have studied:

1) The interaction of the beams with each other, and with the environment. It is concluded that if the beams are at least 10 cm apart, 1 meter long, and carry 10^{-7} to 10^{-9} amperes, the interactions will not interfere with the measurements.

2) The operation of the instrument as a system. This work has included:

   a) Development of system equations as given in the appendix,
   b) Calculation of the effect of beam current variations,
   c) Calculation of the required accuracy of the data sampling system (the analog-to-digital converter),
   d) Estimation of the required thermal stability of all electronic components, and
   e) Calculation of the effect of mechanical offset of the target, and of the offsets to be expected from flexure and thermal expansion of the structure.

B. Electron Gun

The principal design operating characteristics are as follows:

The gun must produce a beam with ≤3 mm diameter at 1 meter for accelerating potentials from 100 to 1600 volts. Beam current must remain between 2×10^{-8} amps to 10^{-9} amps, and the

cathode heater should use ≤1 watt.

The design goals of the gun development were:

1) To achieve the above operating characteristics and simultaneously to:

2) Eliminate all focussing elements except the cathode and anode,

3) Eliminate all potentials except the acceleration voltage and the cathode heater voltage,

4) To make the beam current and diameter nearly independent of acceleration voltage, with constant heater power,

5) To have mechanical stability and reproducibility after disassembly,

6) To have stable operating characteristics over a wide range of temperature and over extended periods of time, and

7) To reduce the weight, size, and power consumption as much as possible.

Design goals 1, 2, 3, and 4 have been achieved in a laboratory gun in which 5, 6, and 7 were ignored. A prototype gun has been built using identical electrical elements in a package intended to satisfy all of the design criteria. In addition to goals 1, 2, 3, and 4, this prototype achieves objective 7; 5 and 6 remain to be demonstrated by an extended test program. The gun has not yet been operated with the latest feedback system. A cross section of this gun is shown in Figures 1-1 and 1-2, and we believe that the design is essentially adequate as an instrumental prototype in its present form.

C. Target

A sectored target has been built consisting of four Faraday cups and a suppressor-repeller wire over the divisions between the cups. The target has been operated with the feedback system described below and appears to be electrically satisfactory. Physically it is not suitable as a prototype due to excess size and weight. A mechanical redesign will be required to adapt this design to the physical requirements of a flight design.

D. Feedback Circuits

A D.C. feedback system was designed and tested at MSC using a focussing type electron gun obtained from the NBS. This system was designed to a resolution of ±.1 volts/meter and achieved a resolution of ±.03 volts/meter in long-term tests of several weeks' duration. A new flight prototype design has been constructed but testing is not complete.

The resolution of ±.001 volts/meter does not appear difficult to achieve with electronics designed to that level; such a design is considered to be well within the state of the art.

E. Other Electronics

Some designs of an analog-to-digital converter have been made, but further work will be required. No work has been done on other portions of the circuitry that are more intimately dependent upon the spacecraft with which the instrument must be integrated. Only the analog-to-digital converter is considered critical enough to the design of the instrument that its operation should be verified by inclusion in an instrumental prototype. All of the

electronics except the feedback circuits are of types which have been included in various spacecraft and are not considered technically difficult.

F. Mechanical Design

Several conceptual designs have been made during the feasibility study by the Rice staff, the MSC-Lockheed contract personnel, and by potential subcontractors contacted for assistance in writing the flight proposal. At least four different designs are considered feasible as the result of preliminary thermal and mechanical design analyses. The best structure arrived at is a rigid, non-folding, "C"-shaped structure. A modification of this structure with hinges would fold and fit inside an "ALSEP" bay. This folding arrangement is shown in the appended proposal. A very clever hinge design was arrived at by one of the potential subcontractors which promises great rigidity and repeatability.

G. Thermal Analysis and Design

Several thermal analyses have been made of the various mechanical structures that were proposed. Two different basic approaches to the thermal control problem appear suitable for the "C" structure, both combining passive and active thermal control.

H. Calibration Facility

A vacuum chamber and associated equipment has been used to test guns and targets in known electric and magnetic fields. This chamber may be quickly converted to take a two-gun, two-target system to test the basic stability of the instrument without its mechanical support.

Another vacuum chamber is available which was used as a calibration facility for the ALSEP/CPLEE instrument. This latter chamber will require modification of its internal structure in order to generate known electric fields, but has a data link to an SDS 92 computer which can automate the test. This chamber is more than large enough to take the entire deployed electric field meter and will have thermal capabilities, after some modification, which allow complete thermal test.

III. Proposed Work

A. The object of the proposed effort is to produce an instrumental prototype detector and to calibrate it thoroughly. This prototype will consist of the following elements:

1) A mechanical structure to accomodate all other parts, and sufficiently rigid and stable over the operating temperature range to permit accurate measurements. The structure will not be hinged but will admit the addition of hinges with a minimum of redesign. It will accept a thermal control system but will not include it. Space will be provided for all necessary circuitry. The structure will be as light as possible, but no exotic metals (such as titanium or beryllium) will be used.

2) A pair of electron guns, using the design already completed, and targets (to make a complete two-beam system) having all necessary operating characteristics and mechanical properties.

3) A feedback system, using the design already completed, and the analog-to-digital converter required to digitize deflection plate voltage; each having the necessary operating characteristics. The circuitry will be of flight design and layout, but will not use

flight quality (selected and burned-in) components. Neither digital control and interface circuitry nor power supplies will be included, but space will be left for these anticipated circuits in the structure.

4) A design of a thermal control system that can be used with the structure provided.

The instrument will be tested and calibrated over the range of fields to be measured and for a period of at least four weeks (a lunar day) to verify both its sensitivity and absolute long-term accuracy. It will be operated over the range of temperatures to be expected within the instrument when the thermal control system is installed. However, complete environmental tests will not be made.

B. At the conclusion of this program, therefore, we will have produced a working instrument from which a flight prototype could be made by:

1) copying the existing circuitry,
2) substituting flight rated components,
3) adapting the mechanical structure to the spacecraft to be employed, and
4) designing interface circuitry.

C. The principal tasks that must be completed to produce this instrument are listed below with the approximate times required for each:

1) Operate the existing gun, target, and feedback circuitry together to insure compatability. In a laboratory test rig, calibrate a single beam system using these elements.
1 January 1971 - 30 April 1971

2) Modify design of gun, target, and feedback system as required, and test.
1 March 1971 - 31 May 1971

3) Operate a complete two-gun system in the laboratory.
1 April 1971 - 31 July 1971

4) Make a detailed thermal study and lay out a mechanical design.
1 April 1971 - 31 July 1971

5) Lay out circuitry to fit mechanical structure.
1 May 1971 - 31 July 1971

6) Fabricate complete two-beam system.
1 August 1971 - 31 November 1971

7) Calibrate complete system.
1 December 1971 - 31 March 1972

8) Write final report and document work accomplished.
1-30 April 1972

IV. Manpower and Budget

A. The principle invertigator has been responsible for the conception and development of this instrument at Rice University since the inception of this project, and will continue in this role. From June 1969 until the present Mr. George Burton, a Space Science Facilities staff scientist has worked full time on the gun development and testing. He has designed the prototype electron gun and the majority of the calibration facility. Mr. Burton will continue to work essentially full time on the proposed development. He will be supported by mechanical and electrical engineers from the Facilities staff, which will also provide technician and machine shop services.

In addition we expect to consult with Dr. F. C. Michel of the Space Science Faculty on some questions relating to the interaction of the instrument with the lunar plasma sheath.

EXPENDITURE FORECAST

COST SUMMARY		FY71	FY72	Totals
Salaries (1)		$20,601	$21,967	$42,568
Overhead @ 57.8% (2)		11,907	12,697	24,604
Material				
LN_2 Gas (2500 liters)	$ 275			
Metal and Ceramic Stock	500			
Electronic Parts	1,000			
Misc. materials	500			
Total	$2,275	2,275		2,275
Equipment				
Magnetic Shield	$3,000			
Digital Volt Meter & Printer	1,800			
Total	$4,800	4,800		4,800
Travel				
2 - 2 man, 3 day trips to Washington D.C.		500	500	1,000
Expenses				
Phone, postage & publications		250	250	500
TOTAL		$40,333	$35,414	$75,747
RICE CONTRIBUTION (See Salary Detail)		$ 1,359	$ 1,441	$ 2,800
Total Program Cost		$41,692	$36,855	$78,547

(1) Detail salary page submitted with one copy of proposal.
(2) Current overhead bid rate subject to change. University FY is July 1 to June 30. Provisional bidding rate represents FY 69 actuals and is not adjusted for future trends in this proposal.

MANPOWER SUMMARY

January 1971 through April 1972

Name Or Classification	FY71 (6 Mo.) M/M	FY72 (10 Mo.) M/M	Totals M/M
P.I. H.R. Anderson	1.5	1.5	3.0
Sr. Engineer	6.0	6.0	12.0
Engineer	2.0	3.0	5.0
Drafting	1.5	1.5	3.0
Machinist	4.0	3.0	7.0
Technician	3.0	3.0	6.0
Secretaries	.5	.5	1.0
Other Contract Liaison	.5	.5	1.0
TOTAL MANMONTHS	19.0	19.0	38.0
TOTAL DOLLARS			
RICE CONTRIBUTION			
P.I. H.R. Anderson	.5	.5	1.0

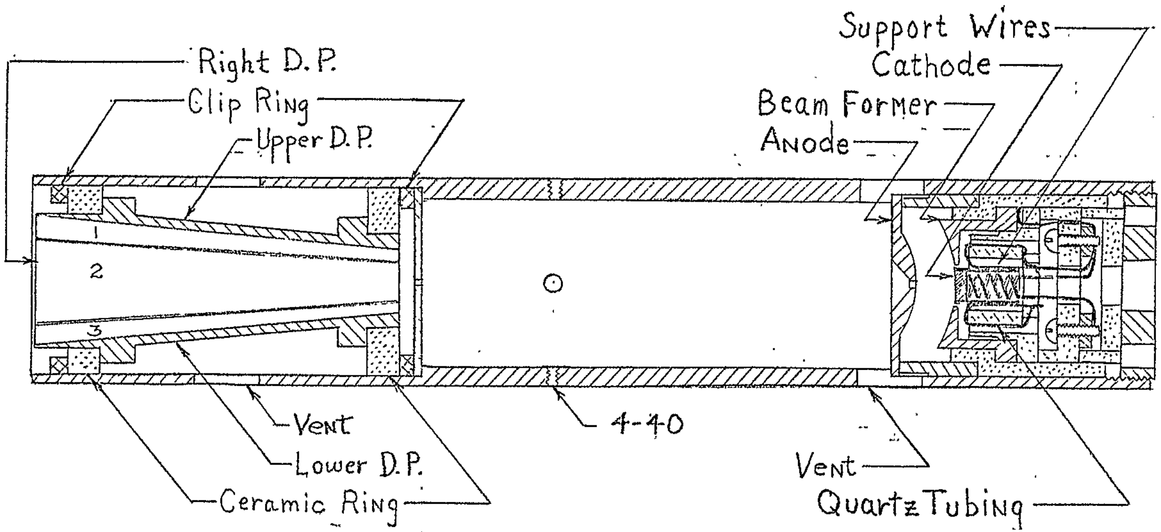

FIGURE 1-1

Scale : X2

# 2	Heater	28	Lower D.P.
3	Heater and Cathode	29	Upper D.P.
14	Ground, Shell and Anode	30	Left D.P.
		31	Right D.P.

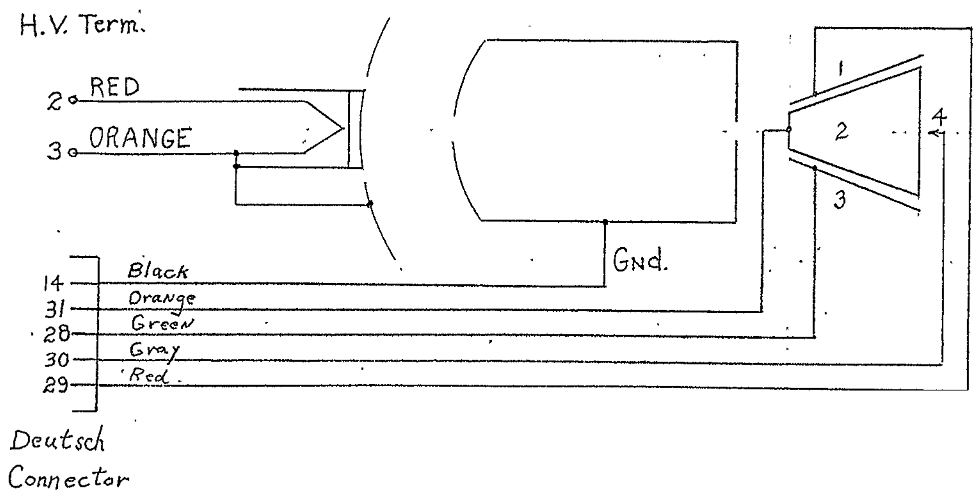

FIGURE 1-2

APPENDIX A-II

SYSTEM EQUATIONS

$$V_g(E) = \left(\frac{L_E E}{4K_1}\right)\left(1 + \frac{1}{H}\right)^{-1}$$

$$V_g(B) = \left(\frac{L_B^2 B}{K_1 L_E}\right)\left(\frac{eV_O}{8m}\right)^{1/2}\left(1 + \frac{1}{H}\right)^{-1}$$

$$V_g(Y_o) = \left(\frac{V_o Y_o}{K_1 L_E}\right)\left(1 + \frac{1}{H}\right)^{-1}$$

$$V_g(e_o) = \left(\frac{D}{2K_1 L_E}\right)\left(\frac{V_o}{I_o}\right)\left(\frac{e_o}{AR}\right)\left(1 + \frac{1}{H}\right)^{-1}$$

$$V_g(I_{OFF}) = \left(\frac{D}{2K_1 L_E}\right)\left(\frac{V_o}{I_o}\right)\left(I_{OFF}\right)\left(1 + \frac{1}{H}\right)^{-1}$$

where : H = Loop Gain $= \left(\frac{2K_1 L_E}{D}\right)\left(\frac{I_o}{V_o}\right)\left(AR\right)$

V_g = output voltage of the gun across the deflection plates

E = Electric Field

B = Magnetic Field

Y_o = Offset distance of gun axis to center of target at the target

e_o = amplifier differential output offset voltage

I_{OFF} = amplifier differential output offset current

L_E = effective beam length in an electrostatic field

I_B = effective beam length in a magnetic field

K_1 = gun constant; range 1.0 to 1.5

$\frac{e}{m}$ = charge to mass ratio of an electron

V_o = beam electron potential

I_o = beam current

D = beam diameter at the target

A = amplifier gain

R = amplifier input resistant

Typical Values

Assume: $L_E = L_B = 1$ meter, $K_1 = 1.0$

$H >> 100$, $e_o = I_{OFF} = 0$

For: $E = 100 \frac{V}{M}$, $V_g = 25V$

$E = 1 \frac{mv}{m}$, $V_g = .25$ mv

For: $B = 100\gamma$ and $V_o = 800$

$V_g = .42$ volts

For: $Y_o = .1$ mm (.004 in) and $V_o = 800$ v

$V_g = .08$ volts

Typical values

V_o - 100 volts to 1.6 Kilovolts

I_o - $1(10^{-7})$ to $1\ (10^{-9})$ amps

D = 1 to 3 mm

A = 10

$R = 10^8$

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